AI-informed Holistic Electric Vehicles Integration Approaches for Distribution Grids

D9.1

Final Western Europe Design

November 2025 (M18)

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EXECUTIVE SUMMARY

This deliverable presents the final design of the Western Europe Demonstrator (WED), one of the demonstrators of the AHEAD project, dedicated to testing innovative approaches for the coordinated management of electric vehicle (EV) charging infrastructure across public, semi-public, and private contexts. The demonstrator is implemented in two Portuguese cities, Funchal (Madeira Island) and Lisbon, each selected to capture distinct e-mobility challenges related to urban, residential, maritime-touristic, and semi-public environments.

In Funchal, the demonstration spans three sites: a Private Multi-Unit Residential Garage, focusing on household-level coordination; a Public Charging Network, integrating flexibility and grid awareness into municipal planning; and a Touristic Port Area, exploring electrification scenarios for maritime-touristic operations. In Lisbon, the EDP Semi-Public Parking Lot serves as a controlled testbed for advanced charging technologies, including matrix-based chargers, V2G, and cybersecure OCPP 2.x communication. For each location, dedicated use cases (UCs) have been defined to validate the different dimensions of smart charging.

The document also defines the demonstrator's technical and computational architecture for each demonstration site. It identifies the technical infrastructures to be deployed, from EVSE installations and smart meters to communication protocols (MQTT, OCPP) and specifies the data flows and interfaces supporting coordinated charging and monitoring. The WED is supported by a modular Data Integration Platform, composed of data sources, source interfaces, central storage, control modules, and user-facing applications. This platform enables seamless interoperability across locations.

Another contribution of this deliverable is the structured assessment methodology, which groups Key Performance Indicators (KPIs) into six thematic categories: System Performance and Responsiveness, Decision and Control Performance, Economic and Environmental Impact, Technology Deployment and Validation, Cybersecurity Assessment, and User and Stakeholder Engagement. These KPIs are systematically mapped to each use case scenario, ensuring targeted and comparable evaluation across demonstration sites.

The document concludes with a reflection on progress and lessons learned, emphasizing challenges in equipment selection, regulatory adaptation, and interoperability, particularly under Portugal's evolving Decreto-Lei n.º 93/2025 on public charging, as well as the importance of early alignment between hardware deployment, data integration, and stakeholder coordination. The next steps include the development of the Port Digital Twin, followed by installation, commissioning, and operation of the demonstrator infrastructure.

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1. INTRODUCTION

1.1. Scope and Objectives

This deliverable defines and consolidates the final design of the Western Europe Demonstrator (WED), one of the key three demonstrators of the AHEAD project. The WED aims to validate innovative approaches for the integration, coordination, and operation of electric vehicle (EV) charging infrastructures across public, semi-public, and private contexts. Focusing on two Portuguese locations — Funchal (Madeira Island) and Lisbon — the demonstrator explores diverse charging scenarios, from residential garages and public networks to semi-public parking lots and maritime-touristic environments.

The objectives of this deliverable are fourfold. First, it details the four demonstration sites (three in Funchal and one in Lisbon) and establishes the timeline of the different project tasks related to the demonstration activities. Second, it specifies the technical and operational architecture required to implement and interconnect the selected use cases, including the definition of equipment, communication protocols, and control systems. Third, it establishes the methodological framework for performance evaluation, identifying a coherent set of Key Performance Indicators (KPIs) and their mapping across the use cases. Fourth, it outlines the integration strategy for AHEAD tools and technologies, such as AI-based planning, flexibility modelling, cybersecurity frameworks, and novel charging hardware, ensuring a consistent and interoperable demonstration environment.

By fulfilling these objectives, the document provides a comprehensive blueprint for the deployment and assessment of smart charging solutions in Western Europe, contributing to the AHEAD project's broader goal of enabling AI-Informed, holistic, resilient, interoperable, and user-centric e-mobility ecosystems.

1.2. Document Structure

The document is structured to move from high-level scope to site-level specifications and evaluation. Chapter 1 (this one) introduces scope, objectives and document structure, while Chapter 2 presents the Western Europe Demonstrator overview (objectives, geographic scope and timeline). Chapters 3–6 provide detailed site descriptions and designs (Chapter 3: Funchal private multi-unit garage; Chapter 4: Funchal public charging network; Chapter 5: Funchal touristic port area; and Chapter 6: Lisbon semi-public parking lot), each covering location, system architecture, bill of materials, data generation and demonstrated use cases. Chapter 7 describes key solutions and technologies (including the Data Integration Platform and AHEAD tools), Chapter 8 defines KPIs and assessment methodologies. Finally, Chapter 9 presents conclusions, progress, lessons learned, risks and upcoming steps.

1.3. Relation to Other Deliverables and Work Packages

This deliverable establishes a crucial foundation for the WED implementation, underpinning subsequent phases and deliverables. The use cases specification and KPI build directly from the work developed in WP1, particularly the scenario and use case formulation in D1.4 [1].

The outcome of this deliverable informs the consortium, especially the partners involved in the WED, with a common understanding of the WED objectives and an overview of the activities and tools to be developed throughout the project. Ultimately, it will serve as a reference for subsequent WP9 tasks, notably those focused on installation, operation, and assessment (T9.3 - T9.6), related deliverables (D9.3 - D9.6) and milestones (MS12 – MS13). The deliverables and milestones defined for the WED are given in Table 1.1.

Table 1.1: Deliverables and milestones directly related to the WED.

Deliverable / Milestone	Project Month	Milestone/Deliverable Name
D9.2	M21	Port Digital Twin, Western demo
D9.3	M24	Installation, Commissioning and Integration, Western demo
D9.4	M45	Operation and Monitoring, Western demo
D9.5	M48	Integration and Coordination of Public and Private EVSEs, Western demo
D9.6	M48	Lessons learned and scaling up, Western demo
MS12	M24	Commissioning and start up, Western demo
MS13	M32	AI based tools tested and first results analysed, Western demo

2. WESTERN EUROPE DEMONSTRATOR OVERVIEW

2.1. Objectives

The Western Europe Demonstrator aims to validate the coordinated management of EV charging infrastructures across distinct urban contexts, showcasing how advanced planning, control, and cybersecurity solutions can enhance flexibility, resilience, and user experience. Specifically, it seeks to:

1. **Demonstrate multi-context smart charging integration** across public, semi-public, and private infrastructures, including residential, municipal, and port environments, using real-world and simulated data.
2. **Validate AI-based tools and digital models** for planning, forecasting, and optimizing EVSE deployment and operation at the city level, ensuring grid-aware, user-centric, and data-driven decision-making.
3. **Evaluate the performance and interoperability of novel charging technologies**, including V1G/V2G-capable systems, and matrix-based chargers, within realistic operational conditions.
4. **Assess the role of cybersecurity in EV charging ecosystems**, testing and validating the robustness of OCPP 2.x implementations and protection mechanisms across hardware and software layers.
5. **Explore the electrification of maritime-tourism activities**, through simulation and digital-twin approaches, to evaluate infrastructure needs, energy demand, and potential flexibility services in port areas.
6. **Engage end-users and stakeholders**, including private garage owners, public charging users, maritime operators, and parking facility managers, to capture perceptions, motivations, and behavioural drivers influencing the adoption of smart charging solutions.

2.2. Geographic Scope and Sites

The WED activities will be held in two different locations in Portugal, namely Funchal (Figure 2.1 – left), and Lisbon (Figure 2.1 – right).

Figure 2.1: Western Europe Demonstrator Locations in Portugal: Funchal (left), Lisbon (right).

The AHEAD demonstration in **Funchal**, located on the Madeira Island (Portugal) aims to validate innovative approaches for the coordinated management of private and public EV charging infrastructure, addressing the priorities of three key stakeholders with complementary yet sometimes competing objectives:

- The Municipality of Funchal, responsible for ensuring that the public charging network is accessible, reliable, and supports broader goals related to urban mobility, sustainability, and liveability.
- The Distribution System Operator (DSO), which must ensure grid stability and power quality, particularly in a geographically isolated system facing increasing and uncertain EV charging demands.
- The EV users, who seeks to charge their vehicle reliably and conveniently to meet personal or commercial mobility needs, often with minimal concern for the underlying grid or city-level constraints.

Funchal's compact urban layout and integration of grid, city infrastructure, and port operations offer a unique setting for testing multi-modal smart charging strategies, including both smart charging (V1G) and vehicle-to-grid (V2G). The port's central role enables experiments beyond road-based mobility, including electrified maritime-tourism with hybrid and electric boats. In parallel, the demo will explore residential charging behaviour in private garages, allowing for an integrated view of urban, maritime, and domestic charging within a geographically constrained energy system.

To operationalize this vision, the Funchal demonstrator is structured around three strategically selected sites, each targeting a distinct use context and stakeholder group:

- **Site 1: Private Multi-Unit Residential Garage.** This site enables the study of private charging behaviour in a residential setting, with a focus on coordination among multiple EV users in a shared infrastructure environment. It provides insights into household-level charging patterns, peak demand management, and the interface between private users and grid needs.
- **Site 2: Public Charging Network Across the City.** The public network demonstration focuses on city-wide charging infrastructure, including EVSEs in public parking lots. The demonstration explores how smart charging can be integrated into urban mobility strategies. It considers both municipal planning objectives (e.g., accessibility, fairness, and efficient use of share resources) and grid-level concerns (e.g., grid congestion, peak loads, and voltage stability), while capturing user behaviour in diverse public settings.
- **Site 3: Touristic Port Area.** Situated in Funchal's city center, this location supports the exploration of maritime-touristic electrification. The focus is on understanding the impacts of introducing electric charging for boats and vessels involved in tourism and leisure activities, in connection with the surrounding urban and grid infrastructure.

The AHEAD demonstrations in **Lisbon** address the increasing demand for EVSEs in parking lots. The pilot explores how advanced parking management strategies, simulating on-site renewable generation, such as rooftop PV, can balance EV user needs with local energy constraints. These strategies also aim to provide coordinated charging that supports both the local electrical infrastructure of the parking facility and DSO operations, enhancing overall system reliability. Recognizing the increasing digital complexity of EV charging systems, the Lisbon pilot will also place strong emphasis on cybersecurity, ensuring safe and reliable access to the infrastructure.

To implement these objectives, the demonstration will take place at the following site:

- **Site 4: EDP Semi-Public Parking Lot.** This pilot site is located within an EDP-managed semi-public parking lot, situated in a laboratorial campus that provides a controlled environment for testing, monitoring, and operating both existing and new EVSE technologies. This setup enables real-world testing of matrix-based charging, which refers to advanced technologies that use either automation or matrix converters to improve the efficiency and user experience of electric vehicle charging, as well as V1G and V2G functionalities. These technologies will be tested with the aim of providing an effective management of the parking facility's electrical infrastructure, while supporting coordination with the DSO.

2.3. Timeline

The Western Europe demonstration activities are divided into six main tasks, as depicted in Figure 2.2: i) specification of the demonstration use cases, ii) development of the maritime-touristic port area digital twin, iii) installation, commissioning and integration, iv) operation and monitoring, v) analysis of results, and vi) lessons learned and scalability.

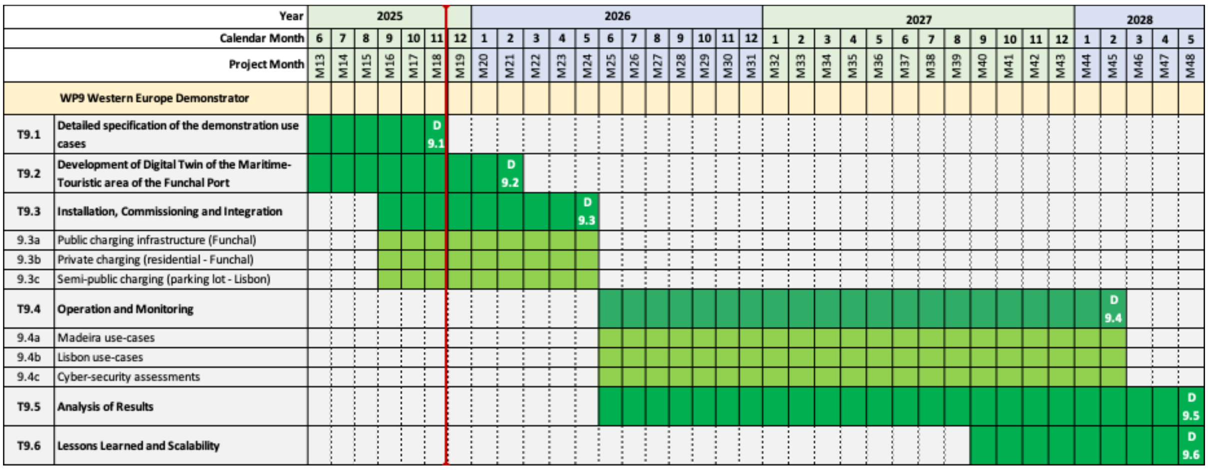


Figure 2.2: Western Europe demonstration time plan.

The **first task**, closing at the end of M18 (November 2025), corresponds to this deliverable and included all the activities related to defining architecture and operational scope of the Western Europe Demonstrator, detailing infrastructure needs, integration plans, and data flows. It also established the KPIs, assessment methodologies, and timelines required to validate each use case, ensuring consistency across all sites.

The **second task**, started in M13 (June 2025) and will last until M21 (February 2026), corresponds to the activities related to the development of a digital twin of the maritime-tourism area in Funchal Port to simulate vessel electrification. This includes the modelling of electric and hybrid tourism vessels, port-side charging operations, and distributed energy resources (DERs). Ultimately, this tool will enable scenario-based analysis and planning for future maritime decarbonization, considering different levels of fleet electrification and charging infrastructure availability.

The **third task**, started in M16 (September 2025) and will close in the end of M24 (May 2026). It covers the infrastructure preparation, deployment, commissioning, and integration of all EVSEs and supporting systems across demonstration sites. It ensures readiness for operation and data collection, integrating novel hardware such as V2G and wireless chargers. This task is further divided into three subtasks, that aggregates the different demonstration sites in Lisbon (site 4) and in Funchal (sites 1, 2 and 3). At this stage some activities have been conclude, namely the preparation of the physical infrastructure in site 4 (EDP Semi-Public

Parking Lot), and the integration of two new EVSEs in the Funchal public charging network (site 2).

The **fourth task** will start in M25 (June 2026) and will last until the end of M45 (February 2028). This task will cover the day-to-day operations, including the execution and follow-up of the different use cases, overseeing the data collection across all sites, and keeping a close contact with the involved stakeholders. Similar to task tree, this task is further divided into three subtasks; the first two subtasks aggregate the activities based in Funchal and in Lisbon, whereas the third task focuses on the cybersecurity demonstration activities, to be developed in close connection with WP5.

The **fifth task** will start in the same month as task four, but it will last until the end of the project (May 2028). In this task, the collected data will be analysed to assess technical feasibility, user satisfaction, and environmental impacts. Computation of the KPIs defined in this deliverable, and user feedback will guide the evaluation of the demonstrated technologies' performance, usability, and sustainability.

Finally, the **sixth task** will start in M40 (September 2027) and last until the end of the project. This task will consolidate the insights from the demonstration activities across the four sites, highlighting technical robustness, user acceptance, and cybersecurity readiness. The findings will inform guidelines for large-scale deployment, and replication of the AHEAD technologies tested in Western Europe.

3. FUNCHAL: PRIVATE MULTI-UNIT GARAGE

3.1. Location and Existing Infrastructure

This site is part of a small residential building with five apartments and a shared garage accommodating four vehicles, two of which are currently electric. One EV charger using a dedicated AC EVSE, while the other relies on a standard power outlet (Mode 1 charging). The garage operates under a separate electricity contract with a peak power limit of 6.9 kVA. Each apartment also has 0.5 kWp of rooftop solar PV installed, providing a relevant context for exploring the interplay between shared residential charging, limited grid capacity, and decentralized renewable generation.

3.2. General System Architecture

A high-level diagram of the existing infrastructure as well as of the planned changes in the scope of the demonstration activities is depicted in Figure 3.1.

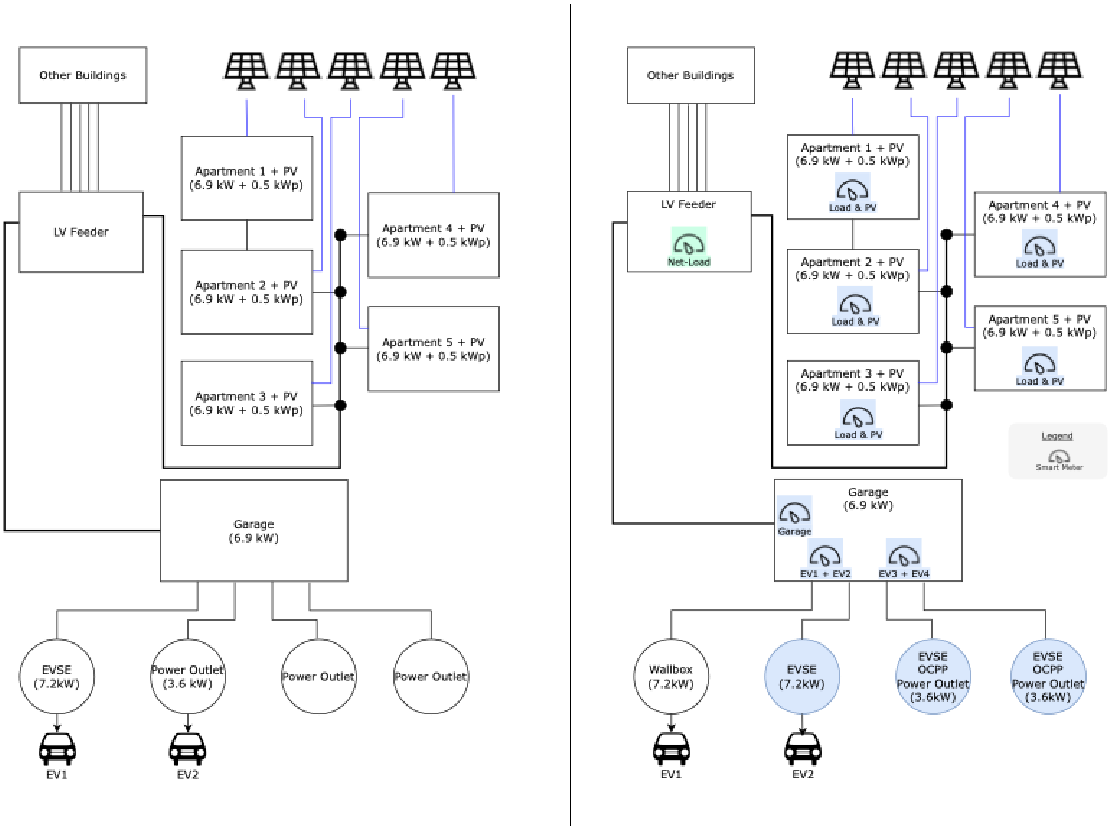


Figure 3.1: High-level diagram of the existing (left) and planned (right) infrastructure for the private multi-unit garage.

As part of the demonstration activities, several infrastructure enhancements will be implemented. Most notably, three new EVSE units will be installed: one 7.2 kW wall-mounted charger and two OCPP-enabled smart sockets, each supporting charging up to 3.6 kW. To enable real-time monitoring of energy consumption, smart meters will be deployed both in the shared garage and in the individual apartments. Additionally, subject to feasibility, a smart meter will also be installed at the secondary substation to provide insights into the overall network loading at the neighbourhood level.

3.2.1. Bill of Materials

Table 3.1 outlines the main components that will be installed or upgraded in the context of the residential garage demonstration. This Bill of Materials (BoM) details the hardware elements required to support smart charging functionalities, local monitoring, and coordination with the wider demonstration infrastructure.

Table 3.1: Private Multi-Unit Garage – Bill of Materials.

Item	Type	Main Parameters	Notes
Alfen single pro EVSE	Mode 3 AC, single-phase, Type 2 socket	Power Output: 7.4 kW single-phase (230 V, 32 A), Nominal Input Voltage: 230 V ±10%, 50 Hz. Authentication Methods: RFID card and Plug & Charge supported. Communication Protocols: OCPP over Ethernet (RJ45) and optionally mobile	New: One unit
Wallbox Pulsar Pro EVSE	Mode 3 AC, single-phase, Type 2 socket	Power Output: 7.4 kW single-phase (230 V, 32 A), Nominal Input Voltage: 230 V ±10%, 50 Hz. Authentication Methods: RFID card and Plug & Charge supported. Communication Protocols: OCPP over Ethernet (RJ45) and optionally mobile	Already on site
Sparklin SPK-ONE (OCPP Plug Socket)	Mode 2 (with 2P + T configuration), single-phase	Power Output: 3.7 kW (single-phase, 230 V, 16 A. Protocol: OCPP.	New: OCPP plug; 2 units
Shelly Pro EM-50	Single-Phase, Dual-Channel	Current Transformers Included: Typically comes with two 50 A CTs. Measurement Accuracy: Class B. Measurements Supported: Active energy, real-time voltage, current, and power, accumulated metrics reported in real-time. Networking: Wi-Fi, LAN (Ethernet), and built-in Bluetooth gateway, all can be used simultaneously. Integration & Control: Local and cloud control via Shelly App or home automation platforms; supports MQTT, WebSocket, UDP, mTLS, and Modbus TCP.	New: One in each apartment; one for the garage; one for each two EVs
Shelly Pro 3EM	Three-phase, LV monitoring	Current Transformers Included: Supplied with three 120 A CTs, enabling monitoring of all three phases simultaneously. Measurement Accuracy: Class B (~1% for active energy). Measurements Supported: Voltage, current, active and apparent power, power factor, and both imported/exported energy. Networking: Equipped with Wi-Fi, LAN (Ethernet), and Bluetooth, which can operate simultaneously. Integration & Control: Full local and cloud management via the Shelly App or third-party platforms; supports MQTT, HTTP(S), WebSocket, secure mTLS communication, and Modbus TCP.	New: For grid-side observability at the distribution cabinet. Pending on the support by the physical infrastructure

Item	Type	Main Parameters	Notes
Router	4G/5G enabled router	Wireless and wired router with support for LAN/WAN and 4G/5G connection via SIM card.	New: provide Internet connectivity in the feeder

3.3. Data Generation and Acquisition

Table 3.2 summarizes the main components, the data they generate, sampling frequency, communication protocols, and where the data is processed.

Table 3.2: Private Multi-Unit Garage – Overview of Data Sources and Key Characteristics.

Component	Data Generated	Sampling Frequency	Communication Protocol	Processed At
Alfen single pro EVSE + Wallbox Pulsar Plus*	Charging session logs, power usage, status, events	1-15 seconds	OCPP	CSMS Remote Backend
OCPP Plug sockets (3.7 kW)	Charging session logs, power usage, on/off status, events	1-15 seconds	OCPP	CSMS Remote Backend
Shelly Pro EM-50	Active/reactive power, voltage, current	5-15 seconds	MQTT	MQTT Broker Remote Backend
Shelly Pro 3EM	Active/reactive power, voltage, current	1-15 minutes	MQTT	MQTT Broker Remote Backend
* This EVSE is already onsite.				

Figure 3.2 illustrates the data flow architecture, highlighting the key protocols and sampling frequencies. For simplicity, only a subset of components is shown; however, the data acquisition and communication processes are analogous for the remaining components.

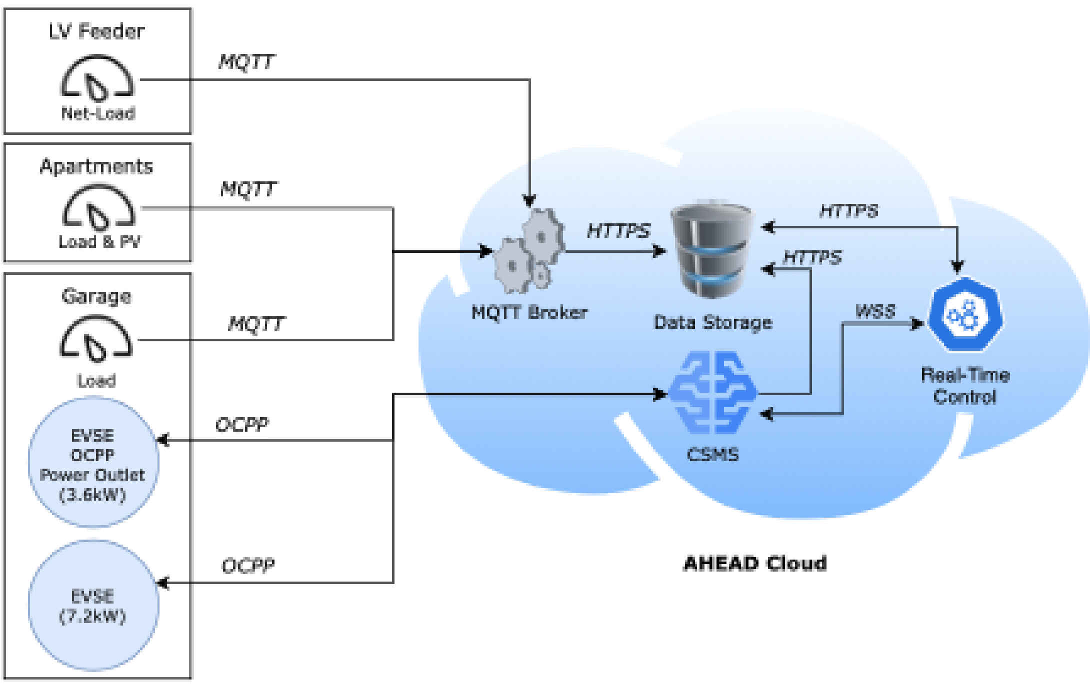


Figure 3.2: Data flow architecture of the private multi-unit garage demonstration site.

Two main communication protocols are used to transfer data from the sources to the cloud: MQTT and OCPP. On the cloud side, several services are executed, including the MQTT broker and the Charging Station Management System (CSMS). All collected data is stored in the cloud via HTTPS-enabled web services. The real-time control communicates with the CSMS via a secure WebSocket (WSS). Additional details about the AHEAD cloud are provided in Section 7.

In this case, MQTT will provide unidirectional communication, where data flows from the meters to the cloud. In contrast, OCPP enables bidirectional communication, allowing data exchange from the chargers to the cloud as well as the transmission of setpoints from the cloud back to the chargers, hence enabling smart charging. Finally, WSS ensures that a communication channel is continuously open between the two components, which is ideal when real-time communications are required.

3.4. Demonstrated Use Cases

In this location the UC2 (charging stations with low-rated capacity) will be tested, namely SUC2.3 aimed at promoting smart management of the available power – which in this case is set by the peak power contract of the garage. This SUC will be tested in three scenarios, as described in Table 3.3.

Table 3.3: Scenarios to be tested in the UC2 at the private multi-unit garage.

ID	Scenario Short Name	Description
SUC2.3-S1	User-centered V1G charging	The main objective of this scenario is to demonstrate the application of V1G charging with low-rated chargers in the context of residential garages. To state more precisely, the smart charging algorithms must ensure that the peak power contract in the garage is not exceeded (presently at 6.9 kVA). The EV owners will be able to start/stop the charging as they need, set their desired schedules, or ultimately rely only on the smart-charging algorithms that will balance the preferences of the EV owners.
SUC2.3-S2	User-centered V1G charging with DSO in the loop	The main objective of this scenario is to upgrade SUC2.3-S1 by incorporating service requests by the DSO. Two types of services will be demonstrated: 1) demand-response (peak shaving and valley filling), 2) local voltage regulation.
SUC2.3-S3	User-centered V1G charging with DSO direct EVSE control	The main objective of this scenario is to demonstrate the possibility of having the DSO directly controlling the EVSEs in the garage. The same services from SUC2.3-S1 will be tested here.

4. FUNCHAL: PUBLIC CHARGING NETWORK

4.1. Location and Existing Infrastructure

This location spreads the entire city of Funchal, covering the entire public charging infrastructure, and focusing particularly on the infrastructure managed by the Funchal City Hall (CMF) and the EEM group.

As of the writing of this deliverable, there are 49 public charging stations in the city of Funchal, for a total of 98 sockets. From these, 19 are locations managed by CMF, for a total of 38 available sockets. The charging stations owned by CMF can be found either on the street or in municipal parking lots. Moreover, two street locations are owned by EMACOM, with a total of 5 sockets. The remaining 27 charging stations are owned and operated by other entities, and can be found in several locations, including gas stations and parking lots.

4.2. General System Architecture

A high-level overview of the existing public chargers in Funchal as well as of the planned ones in the scope of the demonstration activities is depicted in Figure 4.1.

As part of the demonstration activities, six new charging stations will be integrated in the public charging network. This includes one V2G in a public parking lot (11 kW), two V1G stations with 7.4 kW each, one V1G station with 22 kW, and finally two fast V1G chargers that are already installed (45 kW and 60 kW, respectively). Additionally, subject to feasibility, a smart meter will be installed at the main breaker box of the public parking lot to provide insights into the overall loading at building level.

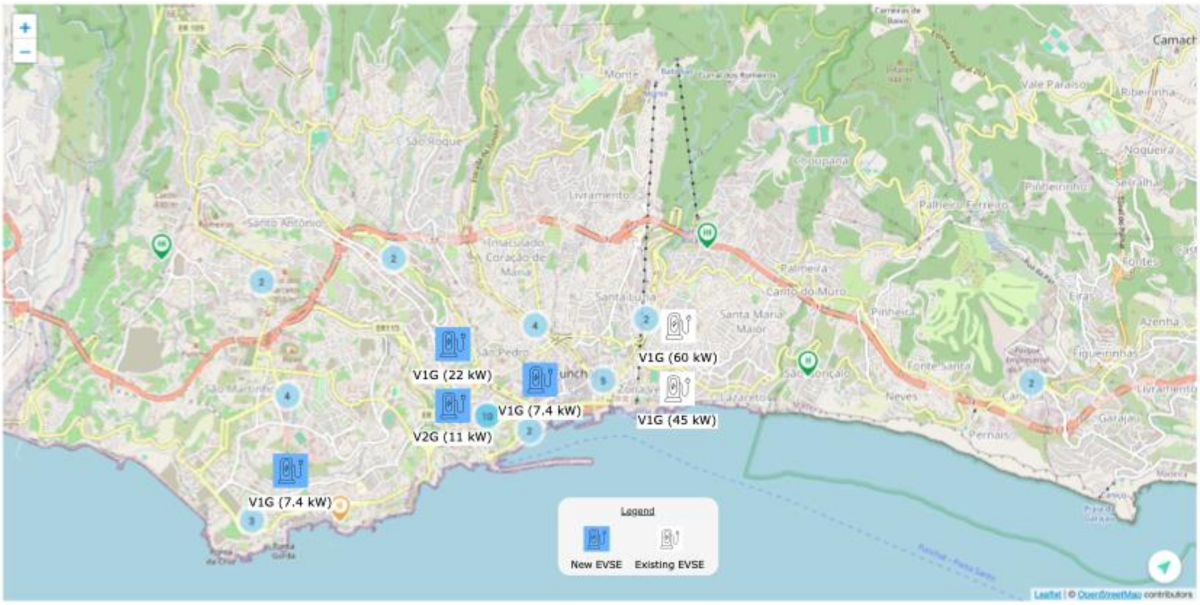


Figure 4.1: Overview of the existing public chargers in Funchal, including the planned ones in the scope of the AHEAD activities.

4.2.1. Bill of Materials

Table 4.1 outlines the main components that will be installed or upgraded in the context of the public charging network demonstration.

Table 4.1: Public Charging Network – Bill of Materials.

Item	Type	Main Parameters	Notes
Latinki11 Home, Bidirectional 11 kW DC Charger for home	CCS (Combined Charging System, IEC 62196-3)	Power Rating: Delivers 11 kW of DC charging power, suitable for efficient home use. Bidirectional Operation: Supports both Vehicle-to-Grid (V2G) and Vehicle-to-Home (V2H) modes; Authentication Methods: RFID card; OCPP: Compatible with OCPP 1.6 JSON (for backend/CSMS integration). Communication Interfaces: Ethernet, Wi-Fi, and 4G (depending on configuration)	New: public parking lot
Alfen single pro tri-phase EVSE	Mode 3 AC, three-phase, Type 2 socket	Power Ratings: Up to 22 kW three-phase (400 V, 32 A per phase) or 11 kW at 16 A per phase. Nominal Input Voltage: 400 V (3×230 V) ±10%, 50 Hz. Authentication Methods: RFID card (ISO/IEC 14443 A/B, MiFare) and Plug & Charge supported. Communication Protocols: OCPP over Ethernet (RJ45), Modbus, DSMR/eSMR P1, with optional mobile connectivity (GPRS/4G, SIM-free).	New: public on street charging
Alfen single pro EVSE	Mode 3 AC, single-phase, Type 2 socket	Power Output: 7.4 kW single-phase (230 V, 32 A), Nominal Input Voltage: 230 V ±10%, 50 Hz. Authentication Methods: RFID card and Plug & Charge supported. Communication Protocols: OCPP over Ethernet (RJ45) and optionally mobile	New: public on street charging; 2 units

Item	Type	Main Parameters	Notes
Shelly Pro 3EM	Three-phase, LV monitoring	Current Transformers Included: Supplied with three 120 A CTs, enabling monitoring of all three phases simultaneously. Measurement Accuracy: Class B (~1% for active energy). Measurements Supported: Voltage, current, active and apparent power, power factor, and both imported/exported energy. Networking: Equipped with Wi-Fi, LAN (Ethernet), and Bluetooth, which can operate simultaneously. Integration & Control: Full local and cloud management via the Shelly App or third-party platforms; supports MQTT, HTTP(S), WebSocket, secure mTLS communication, and Modbus TCP.	New: For grid observability at the building level. Pending on the support by the physical infrastructure
QC45	Three-phase CHAdeMO, CCS and AC Type-2 compliant	Power Ratings: Up to 50 kW (DC Power), 22 kW (AC Power); AC and DC simultaneous charging; Communication Protocols: OCPP (1.5, 1.6); Authentication Methods: RFID card (MiFare); Communication Interfaces: Ethernet, Wi-Fi, and 3G	Already on site for public street charging
QC60	Three-phase CHAdeMO, CCS and AC Type-2 compliant	Power Ratings: Up to 60 kW (DC Power), 22 kW (AC Power); AC and DC simultaneous charging; Communication Protocols: OCPP (1.5, 1.6); Authentication Methods: RFID card (MiFare); Communication Interfaces: Ethernet, Wi-Fi, and 4G	Already on site for public street charging

4.3. Data Generation and Acquisition

Table 4.2: Public Charging Network – Overview of Data Sources and Key Characteristics.

Component / Entity	Data Generated	Sampling Frequency	Communication Protocol	Processed At
Public EVSE	Heartbeats, authentication data, session data	Configurable on the EVSE	OCPP	CSMS
CSMS	session data, EVSE control logs	Based on the EVSE	OCPP / HTTPS	Local / Remote backend (MOBI.E)
MOBI.E	Charging Data Record (CDR)	Per charging session	OCPI	Remote backend (CPO / EMSP)
Shelly Pro 3EM	Active/reactive power, voltage, current	1-15 minutes	MQTT	MQTT Broker (Cloud)

Figure 4.2 illustrates the data flow architecture, highlighting the key protocols. For simplicity, only one EVSE and a smart meter (installed in the public parking lot) are illustrated.

In this setup, two main communication protocols are employed: MQTT and OCPP. Within the AHEAD Cloud, several core services are executed, including the MQTT broker, the CSMS, and the data storage service, which is accessed through HTTPS-enabled web services.

MQTT enables unidirectional communication, with load measurements sent from the meters to the cloud. By contrast, OCPP supports bidirectional communication, allowing the charging stations (EVSE) to send status and transaction data to the cloud, while receiving control setpoints and operational commands from the CSMS. These control setpoints will be calculated in the real-time control module and sent to the CSMS via a WSS connection.

The AHEAD Cloud also interfaces with MOBI.E, which oversees the public charging infrastructure in Portugal. MOBI.E is responsible for services such as authentication and charging session management. MOBI.E is also responsible for communicating with external entities such as the CPO of the EVSE being used (via SFTP), as well as the Electric Mobility Service Provider (EMSP) that is servicing this charging session (via OCPI).

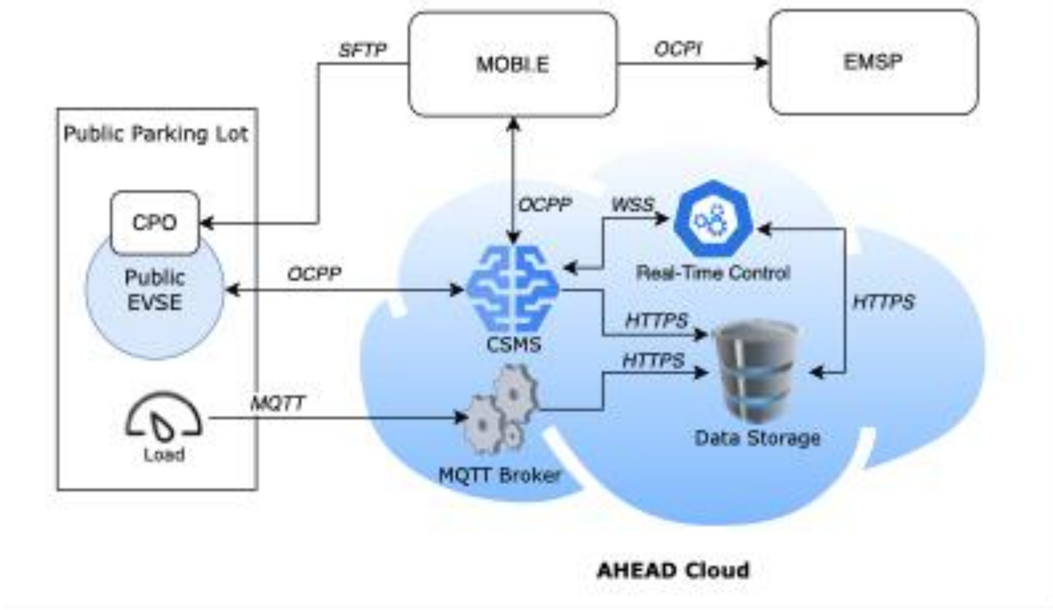


Figure 4.2: Data flow architecture of the public charging infrastructure demonstration site.

4.4. Demonstrated Use Cases

Three UCs will be demonstrated in this location; UC9 (coordinated charging via CPOs), UC11 (activation of flexibility services by DSOs), and UC12 (grid planning with AI tools). Concerning the former, the demonstration will focus on PUCs 9.1 and 9.3 which aim at real-time charging optimization and flexibility service requests via CPOs. As for UC11, the demonstration targets PUC11.1, which aims at real-time grid monitoring from flexibility activation. Finally, the activities for UC12 will focus on PUCs 12.1, 12.2 and 12.3, aimed at spatial mapping models, grid modelling, and AI-based grid planning, respectively.

Table 4.3: Scenarios to be testes in the UC9, UC11 and UC12 in the public charging network.

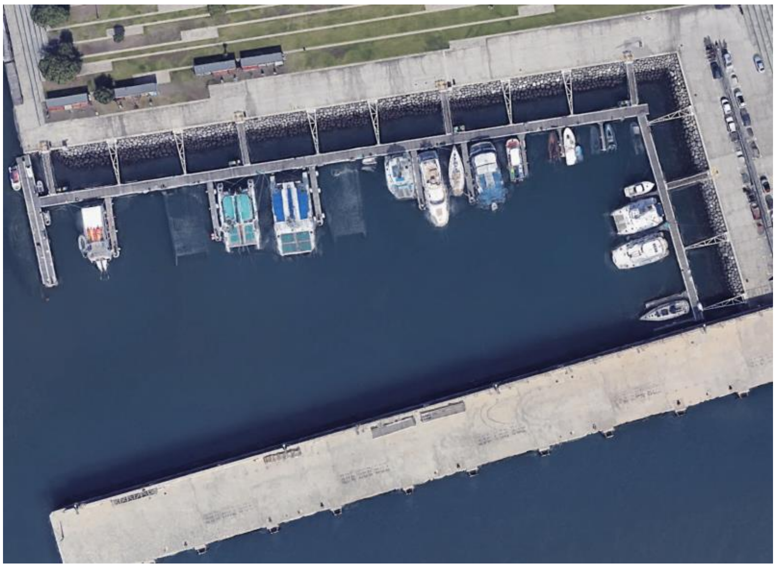
ID	Scenario Short Name	Description
SUC9.3-S1	Public EVSE demand and overstay detection	This scenario focuses on PUC9.1, and the objective is to combine historical and real-time information of the public EV charging network to estimate the power demand in each location and identify charger overstay in the public charging infrastructure. The focus will be the EVSE infrastructure that is owned by CMF, which is operated by different CPOs.
SUC9.3-S2	Public EVSE smart charging via CPOs	This scenario focuses on PUC9.3, and the objective is to demonstrate the infrastructure necessary to reach public EVSEs via CPO request and perform V1G and V2G smart charging. The focus of this scenario will be in the public

ID	Scenario Short Name	Description
		parking lot, where two EVSEs are managed by AHEAD, while the other four are managed by another CPO.
SUC11.3-S1	EVSE-Assisted grid observability	This scenario focuses on PUC11.1, and the objective is to test the ability to see the status of the public and private chargers that can be controlled by the DSO, alongside with existing systems and grid issues that can potentially be mitigated by these chargers.
SUC11.3-S2	DSO-Controlled public/private smart charging	This scenario also focuses on PUC11.1, and the objective is to demonstrate the infrastructure necessary to reach the public and private chargers via the DSO. This will imply communication with the CPOs (for public chargers) and charge point owners (when these are private). Different services will be activated from V1G smart charging (including control of fast chargers) and V2G smart charging.
SUC12.3-S1	Spatial mapping models for EV charging location	This scenario focuses on PUC12.1, and aims to demonstrate how spatial mapping models, EV user charging patterns, environmental and public policy factors can be used to identify the areas with higher demand for charging infrastructure.
SUC12.3-S2	Grid impact assessment for EVSE expansion	This scenario focuses on PUC12.2 and aims to demonstrate how grid models and demand prediction models (general loads and EVSEs) can be leveraged to assess the impact of growing charging station availability in the grid.
SUC12.3-S3	AI techniques for grid planning and optimization	This scenario focuses on PUC12.3, and the objective is to demonstrate how AI techniques can be leveraged to identify and mitigate the trade-offs of maintaining the optimal spatial distribution of chargers while also maintaining the necessary grid stability.

5. FUNCHAL: TOURISTIC PORT AREA

5.1. Location and Existing Infrastructure

The site is in the touristic port area of Funchal's city center, serving maritime leisure operations such as whale-watching trips. The infrastructure accommodates up to ~20 vessels, depending on size (Figure 5.1 – left), of which only one is currently hybrid-powered. It is equipped with electric and water distribution units to meet the vessels basic operational requirements (Figure 5.1 – right) and is supplied by a nearby secondary substation that also feeds other local services.



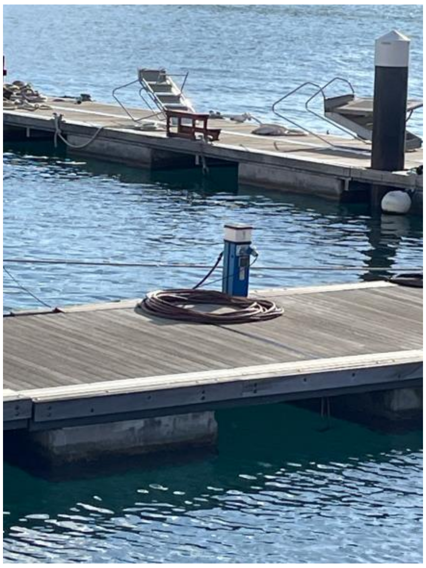


Figure 5.1 Touristic Port Area: satellite view taken from Google Maps in August 2025 (left), power distribution unit (right).

5.2. General System Architecture

A high-level diagram of the existing infrastructure as well as of the planned changes in the scope of the demonstration activities is depicted in Figure 5.2.

To support the demonstration activities, several infrastructure enhancements will be implemented to enable advanced simulations through a digital twin of the touristic port area. This includes building an AC power distribution unit that comprises an EVSE power outlet with 3.6 kW capacity and OCPP support, alongside a standard AC socket equipped with a smart meter to monitor the residual loads on the vessels. Additionally, subject to feasibility, a smart meter will be installed at the secondary substation to provide detailed insights into the overall network loading at the vicinity of the touristic port area.

Complementing the physical infrastructure, key components will be simulated including virtual EVSEs and AC sockets, distributed energy resources (DERs) like storage and solar PV systems. This will be supplemented by a virtual trip simulator, and a simulated charging environment. Together, these physical and virtual elements will be integrated within the digital twin framework, enabling real-time monitoring, scenario testing, and enhancing the demonstration's effectiveness.

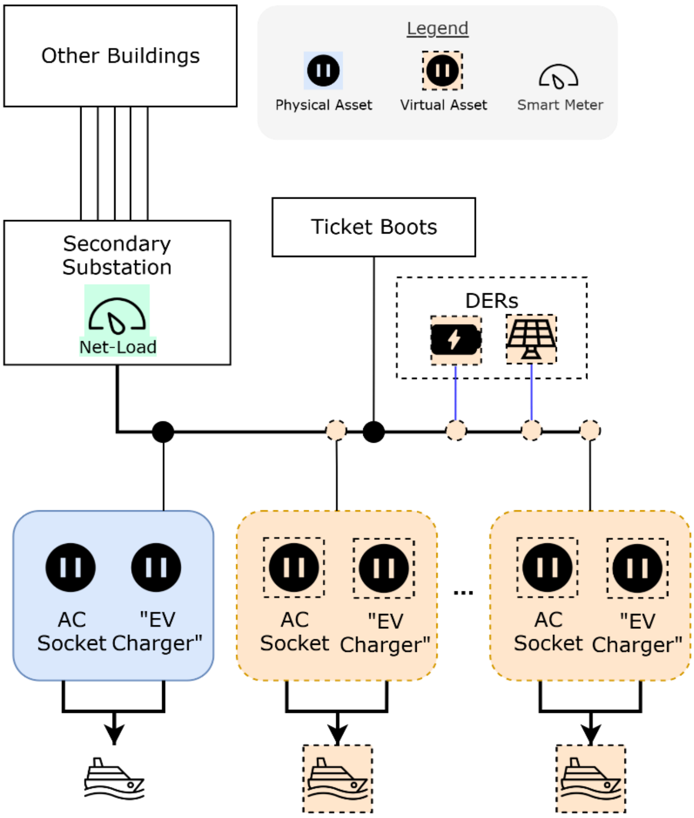


Figure 5.2: High-level diagram of the existing and planned (physical and virtual) infrastructure for the touristic port area.

5.2.1. Bill of Materials

Table 5.1 outlines the main components that will be installed or upgraded in the context of the maritime-touristic demonstration. Note that most of the components are the individual parts that will be used to develop the custom-made EVSE for the maritime-touristic vessels.

Table 5.1: Touristic Port Area – Bill of Materials.

Item	Type	Main Parameters	Notes
Sparklin SPK-ONE (OCPP Plug Socket)	Mode 2 (with 2P + T configuration), single-phase	Power Output: 3.7 kW (single-phase, 230 V, 16 A. Protocol: OCPP.	New: OCPP plug
Shelly Pro EM-50	Single-Phase, Dual-Channel	Current Transformers Included: Typically comes with two 50 A CTs. Measurement Accuracy: Class B. Measurements Supported: Active energy, real-time voltage, current, and power, accumulated metrics reported in real-time. Networking: Wi-Fi, LAN (Ethernet), and built-in Bluetooth gateway, all can be used simultaneously. Integration & Control: Local and cloud control via Shelly App or home automation platforms; supports MQTT, WebSocket, UDP, mTLS, and Modbus TCP.	New: Smart meter

Item	Type	Main Parameters	Notes
TP-Link TL-WPA7517 KIT – AV1000 Gigabit Powerline Wi-Fi Kit	Three-phase	The TP-Link TL-WPA7517 KIT (AV1000) extends network over power lines up to 1000 Mbps (HomePlug AV2), with dual-band Wi-Fi (300 Mbps @ 2.4 GHz + 433 Mbps @ 5 GHz) and 1× Gigabit Ethernet per unit. It supports 128-bit AES powerline encryption and WPA/WPA2 Wi-Fi security, with coverage up to 300 m on the electrical circuit. Works in three-phase installs (best with a phase coupler if outlets are on different phases).	New: Internet connectivity
Smart-MAIC D105 Pulse Counter	Single-Phase	The Smart-MAIC D105 is a compact DIN-rail pulse counter and sensor interface powered by 100–240 V AC single-phase. It features 2 pulse inputs for electricity, water, or gas meters, 1 analog input (0.1–18 V), a 1-Wire port for up to 5 temperature sensors, an RS-485 interface for Modbus devices, and a relay output (50 W). Communication runs via Wi-Fi (802.11 b/g/n) with support for MQTT, HTTP API, and WebSocket, and data is logged in non-volatile memory with intervals from 1 min (default) down to 5 s. Designed for monitoring and automation, it operates from −40 °C to +60 °C in a 2-module DIN-rail housing (90 × 63 × 34 mm).	New: water flow meter

5.3. Data Generation and Acquisition

The demonstration site integrates 3 key components to generate, collect and exchange the pilot data. These components and details of the generated data are presented in Table 5.2, including the data they generate, sampling frequency, communication protocols, and where the data is processed.

Table 5.2: Private Multi-Unit Garage – Overview of Data Sources and Key Characteristics.

Component	Data Generated	Sampling Frequency	Communication Protocol	Processed At
OCPP Plug sockets (3.7 kW)	Charging session logs, power usage, status, events	5–15 seconds	OCPP	CSMS Remote backend
Smart Meters (Socket)	Active/reactive power, voltage, current	5 seconds	MQTT	MQTT Broker Remote Backend
Shelly Pro 3EM	Active/reactive power, voltage, current	1-15 minutes	MQTT	MQTT Broker Remote Backend

Figure 5.3 illustrates the data flow architecture. Again, for simplicity, only a subset of the components is shown.

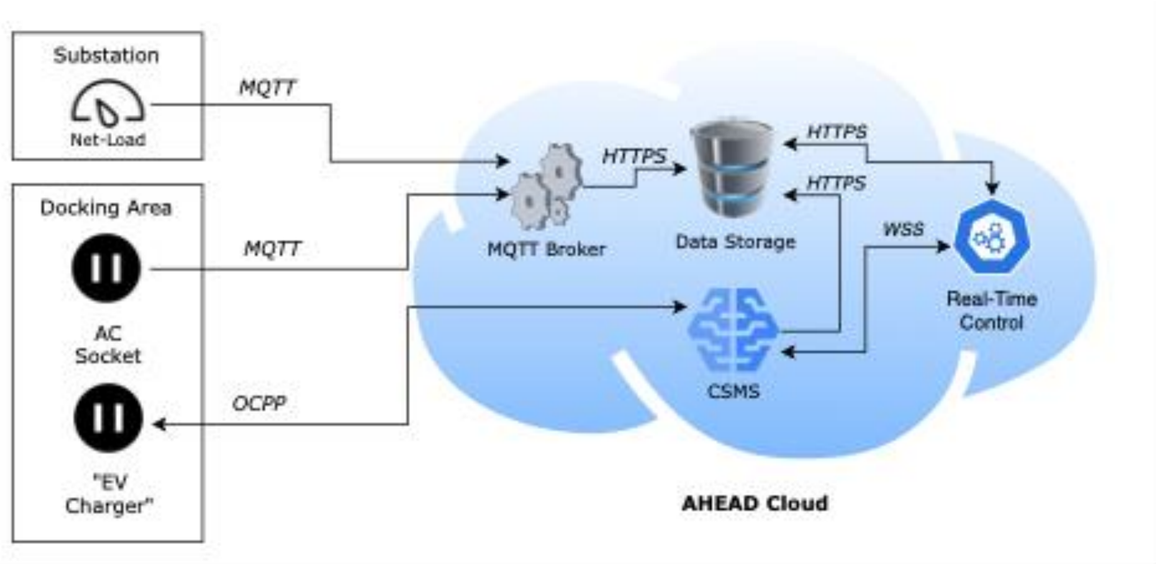


Figure 5.3: Data flow architecture of the touristic port area demonstration site.

In this setup, two main communication protocols are employed: MQTT and OCPP. MQTT is used to push data from the smart meter installed at the secondary substation, as well the electricity consumption monitored in each of the vertical power units installed in the docking area. All the communications related to vessel charging are conducted via OCPP, with a bi-directional setup that enables monitoring and smart charging. Like with the previous cases, the control setpoints will be calculated in the real-time control module, before being forwarded to the CSMS via a secure WebSocket. All the collected data is stored on the AHEAD cloud on a dedicated storage service, which leverages HTTPS webservices.

5.4. Demonstrated Use Cases

Two UCs will be demonstrated in this location, namely UC4 (novel charging technologies), and UC8 (smart charging in port areas). Concerning the former, this location will test SUC4.2 which focused on assessing the technical feasibility of vessel charging technologies. As for the later, three SUCs will be tested: SUC8.1 (Uncoordinated Charging), SUC8.2 (Smart Charging), and SUC8.3 (Grid-aware smart charging). Each SUC will be tested considering different scenarios as described in Table 5.3.

Table 5.3: Scenarios to be testes in the UC4 and UC8 in the touristic port area.

ID	Scenario Short Name	Description
SUC4.2-S1	Vessel charging technologies	The main objective of this scenario is to understand how electric and hybrid catamarans vessels can be charged. In this scenario the entire charging pipeline will be tested, from uncoordinated charging, i.e., the vessels chargers until disconnected or fully charged, and smart charging (i.e., chargers until disconnected or the smart charting objective is reached).

SUC8.1-S1	Uncoordinated charging	This main objective of this scenario, is that through simulation a baseline scenario is established for different levels of vessel electrification (until 100%), without any smart charging in place.
SUC8.2-S1	Smart charging – without DERs	This scenario will upgrade SUC8.1-S1 by enabling smart vessel charging. Since no DERs are available, the objectives of smart charging will be centred around two aspects: 1) reducing peak demand at the secondary substations, and 2) reducing cost of charging by taking advantage of Time of Use Tariffs.
SUC8.2-S2	Smart charging – with DERs	This scenario will extend SUC8.2-S1 by introducing the presence of DERs, namely solar PV and battery energy storage. The smart charging will focus on specific objectives, including costs reduction, peak demand management (inherited from SUC8.2-S1), and maximizing the levels of self-consumption and self-sufficiency.
SUC8.3-S1	Grid-aware smart charging – without DERs	This scenario will extend SUC8.1-S1 by introducing flexibility requests from the DSO. Since DERs will not be available the smart charging will focus on explicit DR will be tested focusing on two aspects: 1) load levelling and peak load shaving, 2) RES maximization, 3) voltage regulation, and 4) frequency regulation.
SUC8.3-S2	Grid-aware smart charging – with DERs	This scenario extends SUC8.3-S1 by introducing DERs on the port side. These DERs, in particular storage, will increase the flexibility potential of the port, but will also introduce potentially conflicting objectives between the DSO and the port manager and vessel operators.

6. LISBON: SEMI-PUBLIC PARKING LOT

6.1. Location and Existing Infrastructure

The site is in an industrial area in the outskirts of Lisbon. The area features a semi-public parking lot servicing a total of 64 charging stations, which are currently managed by a third-party entity. The location lot also features its own secondary substation (630 kVA), servicing the parking lot and nearby buildings.

6.2. General System Architecture

A high-level diagram of the existing infrastructure as well as of the planned changes in the scope of the demonstration activities is depicted in Figure 6.1.

In the scope of the AHEAD demonstration activities, this infrastructure will be upgraded with the installation of two bidirectional EVSEs (one CHAdeMO and one CCS2 both 11kW), as well as one matrix-based charging pad (11 kW). To test the matrix-based charging station, a compliant EV will be retrofitted to support this charging solution. Additionally, subject to feasibility, a smart meter will also be installed at the secondary substation to provide insights into the overall network loading at the parking lot and nearby buildings. Finally, to enable smart charging simulations considering the presence of DERs, a real-time simulation of solar PV production will be implemented.

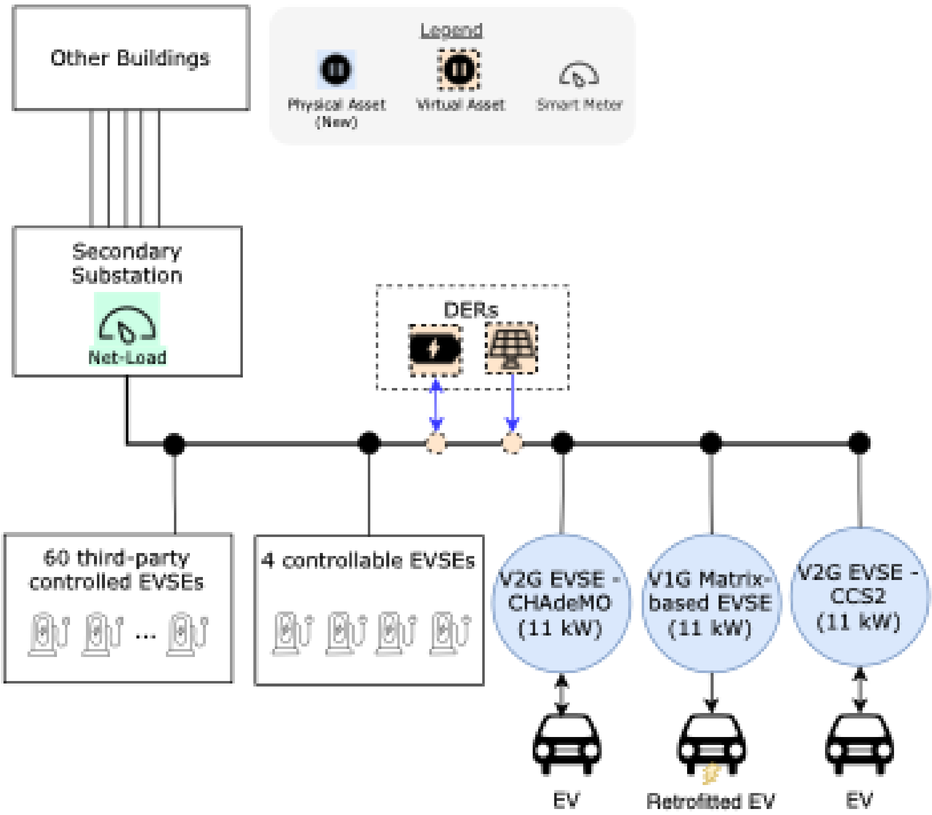


Figure 6.1: High-level diagram of the existing and planned (physical and virtual) infrastructure for the semi-public parking lot.

6.2.1. Bill of Materials

Table 6.1 outlines the main components that will be installed or upgraded on this demonstration site.

Table 6.1: Semi-Public Parking Lot – Bill of Materials.

Item	Type	Main Parameters	Notes
Latinki11 Home, Bidirectional 11 kW DC Charger (V2G CCS2)	CCS (Combined Charging System, IEC 62196-3)	Power Rating: Delivers 11 kW of DC charging power, Bidirectional Operation: Supports Vehicle-to-Grid (V2G); Authentication Methods: RFID card; OCPP: Compatible with OCPP 1.6 JSON (for backend/CSMS integration). Communication Interfaces: Ethernet, Wi-Fi, and 4G (depending on configuration)	New: Fleet charging, public parking lot
PRE-Heliox (V2G CHAdeMO)	Mode 4 DC, CHAdeMO (IEC 62196 AA), Bidirectional (V2G/V2H)	Power Output: 10 kW DC (max), 3-phase 400 V AC input, 28 A DC output, 450 V DC max; Efficiency: 95%; Nominal Input Voltage: 400 V 3-phase, 50 Hz, RFID card (MiFare), OCPP 1.6 JSON (Ethernet RJ45, optional 4G),	New: Fleet charging, public parking lot

Item	Type	Main Parameters	Notes
Matrix Charging System - EV integration	Custom HW: Matrix Charging Pad (MCP) Matrix Charging Switch Cabinet (MCSC) incl. Supply Equipment Communication Controller (SECC) & MCSC Term-Protect (over-voltage conductor + Bus Termination)	Power transfer of 11 kW, Energy Meter installed, OCPP backend to be aligned with EDP, charging mode 3 according to IEC-61851-1, over voltage category III according to EN 60664 (infrastructure), protection type of MCP: IP66, mechanical shock protection IK08, Wifi IEEE 802.11 – 5 GHz, CE-conformity	New: Automatic conductive EV charging
Matrix Charging System – Supply Equipment	Custom HW: Matrix Charging Connector (MCC) Switchbox (MCSB) User Interface (UI) WLAN-Antenna	Power transfer of 11 kW, charging mode 3 according to IEC-61851, over voltage category II according to EN 60664; protection class IP6K6K (MCC), IP6K7 (MCSB), IP55 (MC automatic connector – inside MCC), mechanical shock protection ISO16750/LV124, UI type: Samsung Galaxy A33, Wlan Antenna: 2J5502P-500LL100-C872_CU008051, Wifi IEEE 802.11 – 5 GHz, CE-conformity	New: Automatic conductive EV charging
Inch Pro (model GPC15BY40)	Mode 3 AXC, Type 2 (IEC 61851)	Power Output: 22 kW three-phase (230/400 V, 32 A); Authentication Methods: RFID card and Plug & Charge supported; Communication Protocols: OCPP over Ethernet (RJ45), optional mobile connectivity; Nominal Input Voltage: 230/400 V~, 50 Hz; Current: 32 A max	Existing and controllable; 4 units
Shelly Pro 3EM	Three-phase, LV monitoring	Current Transformers Included: Supplied with three 120 A CTs, enabling monitoring of all three phases simultaneously. Measurement Accuracy: Class B (~1% for active energy). Measurements Supported: Voltage, current, active and apparent power, power factor, and both imported/exported energy. Networking: Equipped with Wi-Fi, LAN (Ethernet), and Bluetooth, which can operate simultaneously. Integration & Control: Full local and cloud management via the Shelly App or third-party platforms; supports MQTT, HTTP(S), WebSocket, secure mTLS communication, and Modbus TCP.	New: For grid observability in the area. Pending on the support by the physical infrastructure
Router	4G/5G enabled router	Wireless and wired router with support for LAN/WAN and 4G/5G connection via SIM card.	New: (if needed) provide Internet connectivity in the substation

6.3. Data Generation and Acquisition

Table 6.2 summarizes the main components, the data they generate, sampling frequency, communication protocols, and where the data is processed.

Table 6.2: Semi-Public Parking Lot – Overview of Data Sources and Key Characteristics.

Component	Data Generated	Sampling Frequency	Communication Protocol	Processed At
Four chargers (ETREL Inch Pro)*	Heartbeats, authentication data, session data, error codes, status updates	Configurable (typically 15s–1min)	OCPP 1.6	CSMS Local backend
Matrix Charging system	Power transfer between power supply and EV, communication between EVCC and SECC	Real time, session or periodic	Custom protocol based on OCPP 1.6, internal CAN communication	Vehicle Unit (Matrix Charging Connector) and Supply Equipment Unit (Matrix Charging Pad)
V2G Charger	Session data, authentication, charge/discharge logs, grid-balancing, error codes	Configurable (real-time, session, or periodic)	OCPP 1.6/2.0	CSMS Remote Backend
Shelly Pro 3EM	Active/reactive power, voltage, current	1-15 minutes	MQTT	Remote Backend

* These four EVSEs are already onsite.

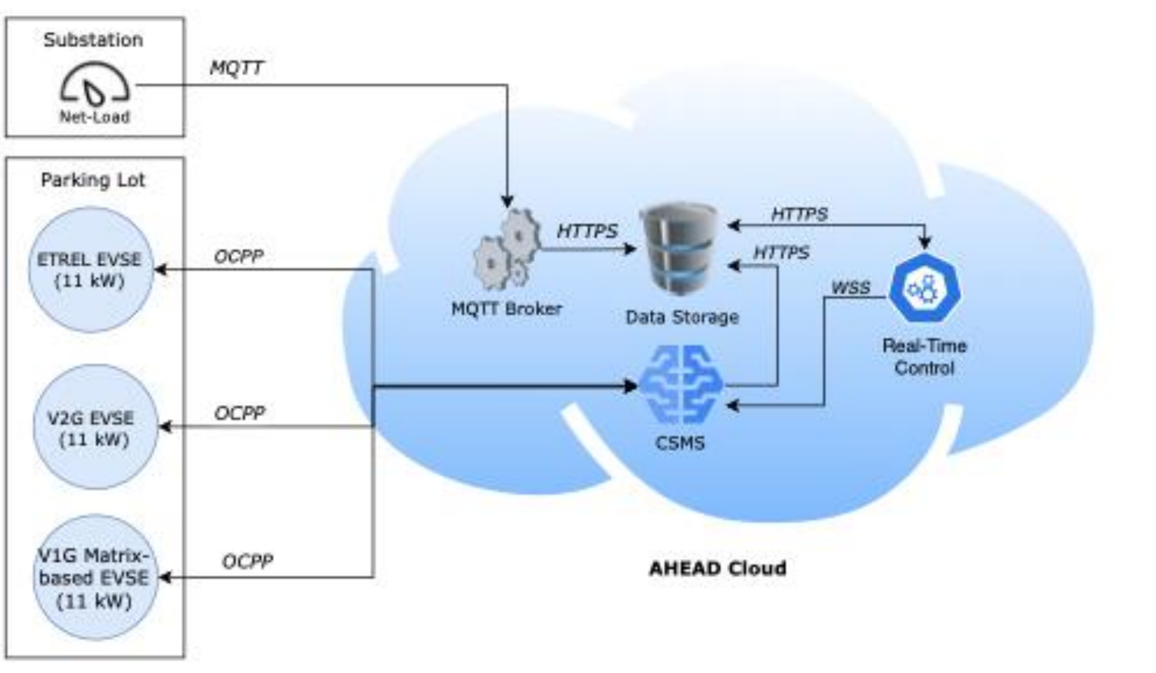


Figure 6.2: Data flow architecture of the semi-public parking lot demonstration site.

As in the previous demonstration sites, MQTT and OCPP are the main communication protocols that will be employed. Load measurements are transferred to the AHEAD cloud via MQTT, in a unidirectional flow from the meter installed in the secondary substation to the cloud. OCPP, in contrast, enables bidirectional communication, allowing the chargers to send operational data to the cloud (via CSMS) while receiving setpoints and control commands from the CSMS via the real-time control.

6.4. Demonstrated Use Cases

Four UCs will be demonstrated in this location, namely UC2 (charging infrastructures with low rated capacity), UC3 (cyber-secure charging platform), UC4 (novel charging technologies), and UC5 (smart charging in workplaces). Concerning UC2, in this site SUC2.3 will be tested, focusing on optimizing concurrent low-rated EV charger for speed, cost and grid stability. In the case of UC3, SUC3.3 will be tested with a focus on exploring the benefits of the new cyber-security features available in OCPP2.X – particularly OCPP2.0.1. Concerning UC4, this site will serve to demonstrate the matrix-based charging technology. Finally, UC5 will focus in SUC5.1A (aiming to maximize self-consumption from RES), and SUC5.3A (responding to dynamic prices from the DSO). An overview of the different scenarios for each SUC is provided in Table 6.3.

Table 6.3: Scenarios to be testes in UC2, UC3. UC4 and UC5 in the semi-public parking lot.

ID	Scenario Short Name	Description
SUC2.3-S1	Concurrent Charging – without DERs	The main objective of this scenario is to test the control of low-rated chargers in the parking lot – in this case, the lowest rated charger is of 11 kW. To state more precisely, a smart power sharing algorithm will be developed to control the 4 controllable chargers with the objective of optimizing the power distribution across the parking lot to avoid circuit and secondary substation overloading.
SUC2.3-S2	Concurrent Charging – with DERs	This scenario extends SUC2.3-S1 via simulation to optimize the power sharing algorithm considering the presence (also through simulation) of DERs, namely PV and battery energy storage.
SUC3.3-S1	OCPP 2.X as a potential mitigation to attacks developed on OCPP 1.6	The objective of this scenario is to understand the impact of using OCPP2.X as a potential mitigation for the known attacks available for OCPP1.6. The focus will be primarily on the authentication capabilities and default cyber-security measures available in OCPP2.0.1. (e.g., transport layer security and dedicated event logging).
SUC3.3-S2	Threats against chargers using OCPP2.X	The objective of this scenario is to demonstrate the impact of potential threats aimed directly at OCPP2.x enabled charging station and to test the cybersecurity enabled by OCPP2.X.
SUC4.1-S1	Matrix-based charging technologies	The main objective of this scenario is to understand how matrix-based charging can be operated. In this scenario the full charging pipeline will be tested, from uncoordinated charging, i.e., the EV chargers until disconnected or fully charged, and smart charging (i.e., the charger is disconnected when the smart charging objective is reached).
SUC4.1-S2	V1G in matrix-based charging technologies	This scenario extends SUC4.1-S1 by introducing the V1G capabilities of the matrix-based charger. Again, the full charging pipeline will be tested with a focus on the activation and interruption of the V1G functionality.
SUC5.1A-S1	Maximize self-consumption from RES	The main objective of this scenario is to develop and test smart charging algorithms that can coordinate the controllable chargers in the parking lot such that the self-consumption from RES is maximized, while ensuring that the EV charging requirements are met.
SUC5.3A-S1	Dynamic pricing	The main objective of this scenario is to develop smart charting algorithms that can coordinate the controllable chargers while responding to dynamic prices set by the DSO. The dynamic prices will the settled one hour-ahead.

ID	Scenario Short Name	Description
SUC5.3A-S3	Dynamic pricing with RES	This scenario extends SUC5.1A-S1 by introducing the need to respond to dynamic prices while maximizing the self-consumption from RES.

7. KEY SOLUTIONS AND TECHNOLOGIES

7.1. Data Integration Platform Overview

A key component of the Western Europe demonstrator is the data integration platform, which was designed such that we can support the different activities to be developed in Funchal and in Lisbon, as well as to provide data to interested third parties.

The data integration platform revolves around five key concepts, illustrated in Figure 7.1. The **Data Sources** represent any source of data to be integrated. Since many different sources of data may exists, another key component are the **Data Source Interfaces (DSI)**, which are responsible for collecting the data from the data source and storing in into the **Data Storage** component. In some special cases, e.g., when the data source supports OCPP, the DSI is also able to write in it. The **Control Modules** (including operation planning and real-time control) component provides the intelligence of the system and is where control and other supporting algorithms reside. Finally, the **External Applications** component represents all the applications that will rely on the data and other functionalities of the platform.

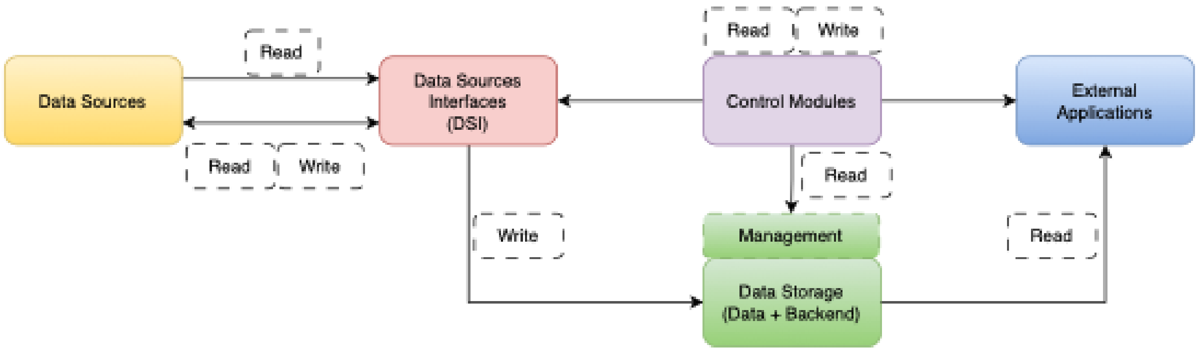


Figure 7.1: Overview of the Data Integration Platform.

7.2. Data Integration Platform Implementation

The implementation of the data integration platform is a continuous effort throughout the project, with several components already implemented or planned, as illustrated in Figure 7.2. A brief description of the different components is presented in the following subsections.

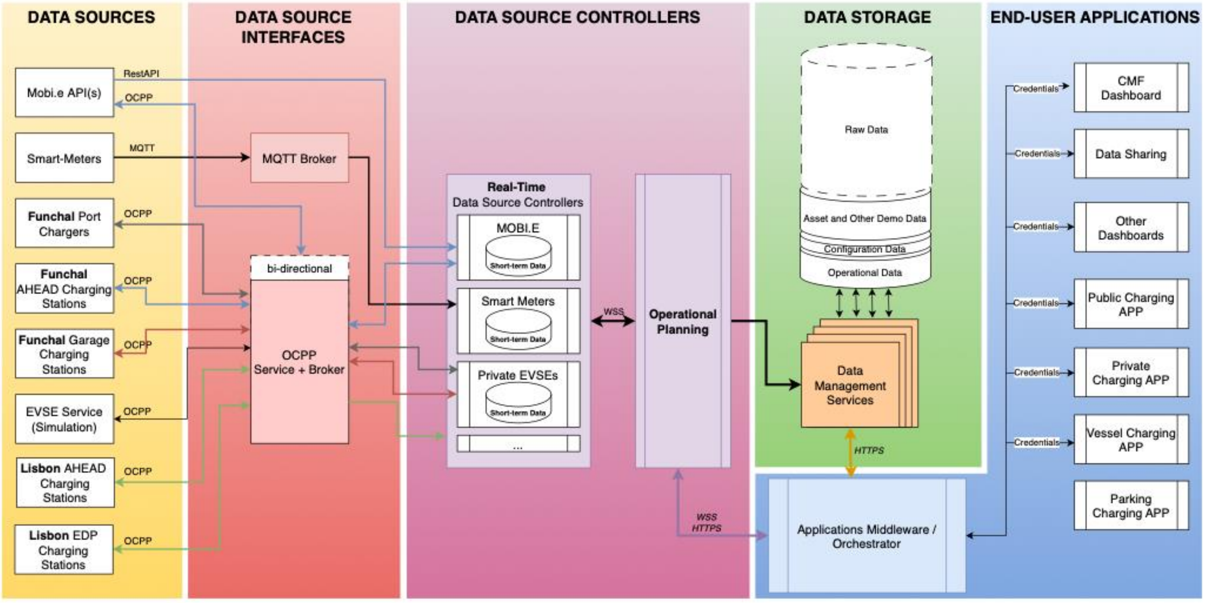


Figure 7.2: Overview the modules implemented and planned in the Data Integration Platform.

7.2.1. Data Sources

Data sources are the origin points of information within the AHEAD platform, encompassing public and private EVSEs, smart meters, simulation services, and external APIs (e.g., Mobi.e). These sources may be read-only (e.g., weather or Mobi.e APIs providing data via HTTPS), or bi-directional (read-write) such as OCPP-based EVSEs and MQTT-based smart meters, which support both data collection and command operations. The diagram also includes simulated EVSE services, which will be used in test and demonstration of scenarios that cannot be tested in real-world assets.

7.2.2. Data Source Interface

The data source interfaces are communication layers that connect the AHEAD platform with its underlying data sources. As shown in the diagram, these include OCPP brokers/services (for EVSEs) and MQTT brokers (for smart meters), enabling real-time data exchange. Additionally, REST APIs (e.g., Mobi.e) and HTTPS/WSS protocols support secure access and data transfer from web-based and external services.

7.2.3. Data Source Controllers

Data source controllers handle the control and coordination of data sources that support write operations. The diagram distinguishes between real-time controllers, which manage immediate interactions with connected EVSEs and smart meters, and operational planning, which handles x-day-ahead scheduling and strategy execution for assets such as AHEAD and private chargers. These controllers ensure that operational commands, forecasts, and optimization results are consistently propagated across all sites (e.g., Funchal Garage, Port, and Lisbon). Note from the diagram, that each real-time controller also maintains a dedicated temporary database, used primarily to store short-term or transient data required for real-time operations, such as state updates, event buffering, or local optimization variables.

7.2.4. Data Storage

The data storage layer contains all modules and services necessary to store, organize, and manage project data. As represented in the diagram, the AHEAD platform distinguishes between:

- *Operational data*, covering day-to-day activities, including user credentials, sessions, and real-time records;
- *Configuration data*, containing static definitions such as MQTT namespaces and system parameters;
- *Asset and demo data*, encompassing pre-processed datasets like aggregated time series for smart meters, forecasts, and simulation outputs;
- *Raw data*, storing all unprocessed values collected directly from data sources.

Note that the relative sizes of the databases in the diagram indicate the expected volume of data each database.

7.2.5. End-User Applications

End-user applications represent the interfaces through which stakeholders interact with the AHEAD platform. As shown in the diagram, these include dashboards and mobile/web apps, built for different user roles (garage operators, DSO, municipality, port, and parking managers).

Between the application layer and the data management services lies the Applications Middleware / Orchestrator, which is responsible for coordinating data flows, handling authentication, and enforcing communication protocols (e.g., HTTPS/WSS). This middleware ensures that all dashboards and apps can securely access the required operational and configuration data while maintaining consistency across distributed services.

Examples of dashboards include:

- *BirdsEViewGarage*, providing administrative views of garage operations;
- *BirdsEViewDSO*, offering modules for Garage, Port, City Chargers, hence providing the DSO with an integrated view of the all the pilot sites;

- BirdsEViewMunicipality, designed to visualize city-level assets such as CMF chargers; this dashboard will be used by the municipality services responsible for the mobility and transport in the city of Funchal;
- *BirdsEViewPort*, supporting port monitoring and management; this dashboard will be mainly used for simulation purposes and user studies with maritime-touristic company operators in Funchal;
- *BirdsEViewParkingLot*, enabling control, smart charging, and RES simulation.

Examples of user-facing apps include:

- *BirdsEVGarage-EVOwner*, providing options for manual scheduling, smart charging, DSM, and direct control;
- *BirdEViewPublic-EVOwner*, allowing users to activate and manage AHEAD chargers;
- *BirdsEViewPower-ParkingLot*, enabling EV charging management and smart operation in semi-public parking lots.

Altogether, these examples illustrate the range of end-user applications supported by the AHEAD platform to be used in the Western Eurore Demonstrator, all relying on credential-based access and secure communication channels (HTTPS/WSS) coordinated through the middleware layer. All dashboards and applications will be further specified and detailed in subsequent AHEAD work package deliverables, namely, D9.4, D9.5, and D9.6, where their functionalities, user interactions, and integration mechanisms will be described more comprehensively.

7.3. AHEAD Solutions

A number of tools and models developed under AHEAD framework will be leveraged in the Western Europe Demonstrator. These tools, developed across multiple work packages, span from grid and flexibility modelling to cybersecurity and digital twin environments, providing a cohesive ecosystem for testing the demonstration scenarios.

At the data and modelling layer, two key tools from WP4 – the Grid Models (T4.3) and Hosting Capacity Model (T4.4) – form the analytical foundation of the demonstrator. The grid models represent the distribution networks, including the EVSE loads, and enable testing of flexibility services defined in WP3. The hosting capacity tool builds on these models to map available electrical capacity across network nodes, providing municipalities and planners with insights into where new EVSE can be safely deployed.

Building on this foundation, AI-based analytical tools developed in WP3 and WP6 will support strategic and operational decision-making. The Clustering and Forecasting Tools (T3.3) will characterize EV-related flexibility and generate demand and availability forecasts to support grid operators. Complementing these, the AI-Based Planning Tool (T6.1) will integrate these forecasts with spatial and grid data to recommend optimal charging station locations. For the case of the Public Charging Infrastructure, a light version of the AI-Based Planning Tool will be developed to support short- and medium-term decisions, including features aimed at democratizing the access to public charging infrastructrures. Two features are particularly relevant in this case, the ability to map traffic to the rate of utilization of EVSEs, and the possibility of detecting overstay in the public charging infrastructure.

At the technology and hardware layer, innovations from WP2, most notably the Matrix-Based Charger (T2.3), will be deployed and tested in the semi-public parking lot in Lisbon. These will serve as reference for future usage of wireless charging technologies, showcasing the efficiency and applicability of these new technologies in real-world charging scenarios. Another critical technlogy that will be tested are digital twins. More precisely, the Digital Twin of the Maritime-Tourism Area of Funchal Port (T9.2, SHIFT2DC) will serve as a high-fidelity environment for integrating and validating the AHEAD AI-based algorithms. Moreover, the Digital Twin will be complemented with a custom made low-cost charging solution of maritime-touristic vessels, which will also serve as reference for future usage of charging technologies under realistic maritime and tourism-related conditions.

Finally,given the increasing connectivity of these systems, cybersecurity tools developed in WP5 will be instrumental in the semi-public parking lot pilot. The Threat Models (T5.2) will be used to assess the exposure of the demo scenarios to known and emerging cyber threats, while the Cybersecurity Requirements (T5.3) will provide a framework of preventive and reactive measures ensuring system resilience and compliance with current standards. Together, these will ensure that the developed solutions are robust and secure under realistic operating conditions.

8. KPIS AND ASSESSMENT METHODOLOGIES

Numerous Key Performance Indicators (KPIs) were initially defined in Deliverable D1.4 (Scenario and Use Case Formulation). This section refines and extends that work by presenting a selected subset of KPIs that are most relevant for assessing the performance of the use cases demonstrated in the Western Europe Demonstrator.

8.1. Key Performance Indicators

To support clarity and coherence, the KPIs have been grouped into six thematic categories, each reflecting a specific evaluation dimension (e.g., system performance, decision-making effectiveness, sustainability impact). Within each theme, a table provides the KPI name and a brief description.

Given that many KPIs apply across multiple use cases (see 8.2), their specific formulations and calculation methods may differ depending on the context. Detailed definitions, including computation methods, baselines, and data sources, will be provided in subsequent deliverables – D9.3 (Installation, Commissioning and Integration, Western), D9.4 (Operation and Monitoring, Western), and D9.5 (Integration and Coordination of Public and Private EVSEs, Western). Moreover, it should also be noted that, while this list is already extensive, additional KPIs may be introduced during the demonstration phase, as new requirements or insights emerge from real-world testing and stakeholder feedback.

8.1.1. System Performance and Responsiveness

These KPIs measure the physical and operational behavior of the system during flexibility events, including power and energy impacts, charging efficiency, and the responsiveness and reliability of the deployed infrastructure

Table 8.1: System Performance and Responsiveness KPIs.

KPI	Name	Description
1	Peak Load Reduction	The percentage of reduction in peak power considering different aggregation points, e.g., grid, secondary substation, feeder and building.
2	Valey Reduction	The percentage of reduction in load valleys considering different aggregation points, e.g., grid, secondary substation, and feeder.
3	Power/Energy Shifted in Time	The amount of power (or energy) shifted in time because of an explicit or explicit demand-respond action.
4	Power/Energy Shifted in Amplitude	The amount of power (or energy) curtailed because of an explicit or explicit demand-response action.
5	Charging efficiency	Percentage of power utilization for charging considering the maximum power available.
6	EVSE uptime	Percentage of time that the charging station are operational.
7	Activation Time	Average time from grid stress detection to transmission and activation of the command.
8	Delay time	The time required to adjust the power setpoint. To be measured at different points of the pipeline, e.g., OCCP server and EVSE.

8.1.2. Decision and Control Performance

These KPIs measure the performance and accuracy of planning, forecasting, and control mechanisms that drive flexibility actions. They evaluate how effectively decisions are made, how accurately they reflect system needs, and how efficiently control signals are executed.

Table 8.2: Decision and Control Performance KPIs.

KPI	Name	Description
9	Charging Duration Variability	Quantifies the difference in duration of the charging sessions with and without smart charging.
10	Charging SoC Variability	Quantifies the differences between the requested/expected SoC with and without smart charging.
11	Power/Energy Regret	Measures the amount of power (or energy) wrongly shifted in time or curtailed as a response of an explicit or implicit demand response action.
12	Power/Energy Loss of Opportunity	Measures the amount of power (or energy) that could have been shifted or curtailed shall the explicit or implicit demand response request was optimal.
13	Improvements in Grid Observability	Measures the grid issues that are identified due to the availability of real-time and forecast measurements in different points of the LV grid.
14	Identification of the needed flexibility	Flexibility requests (in time and power) due to EV charging requirements. Can be measured in real-time or predicted (e.g., day-ahead).
15	Flexibility Regret	Measures the flexibility requests that were not accurate either as a request for a shift in time or a power curtailment.
16	Flexibility Loss of Opportunity	Measures the flexibility requests that could have been made, either as a request for a shift in time or a power curtailment, shall the flexibility identification was optimal.
17	Areas correctly identified	Assesses whether the AI model produces reliable estimates of the best areas to install new EVSEs considering different grow-rates in EV adoption.
18	Impacts correctly assessed	Assesses whether the AI model produces reliable estimates of potential grid issues due to increase need for EV charging, considering different grow-rates in EV adoption.
19	Trade-offs correctly identified	Assesses whether the AI model is able to correctly identify trade-offs between maintaining optimal spatial distribution of chargers while also maintaining the necessary grid stability.
20	Overstay Correctly Detected	Measures the number of overstays in the EVSE, indicating potential miss usage of the public infrastructure.

8.1.3. Economic and Environmental Impact

This category captures the tangible economic and environmental outcomes of the system's operation. It evaluates how flexibility actions contribute to lowering emissions, optimizing energy costs, and improving overall resource efficiency.

Table 8.3: Economic and Environmental Impact KPIs.

KPI	Name	Description
21	Energy cost savings	Reduction in electricity cost with optimized scheduling
22	Rewards Received	Quantifies the total rewards received by an EV owner due to participation in services. This can be for example a token in appreciation to allow smart charging, where the token is adjusted based on the amount of power/energy shifted in time or curtailed.
23	CO_2 reduction	Measures the amount of CO_2 reduction as a result of smart charging, especially when considering the availability of DERs. It will also be estimated for scenarios where peak-load and load valleys are reduced.
24	Self-Sufficiency	The proportion of the charging station's total energy demand is covered by on-site RES and BESS, reducing reliance on the grid.
25	Self-Consumption	The proportion of RES that is consumed locally for EV charging instead of being exported to the grid.
26	Number of EVSEs Supplied by RES	The number of EV chargers that are actively using RES energy as their primary power source.

8.1.4. Technology Deployment and Validation

This category includes KPIs that evaluate the deployment and validation of the developed charging technologies. It captures the number of systems retrofitted, commissioned, and successfully tested under real operational conditions.

Table 8.4: Technology Deployment and Validation KPIs.

KPI	Name	Description
27	Retrofitted EVs	Number of EVs retrofitted to support wireless charging technology. At least one EV should be successfully retrofitted and tested. The target is one.
28	Retrofitted EVSEs	Number of EVSEs retrofitted and integrated in the demonstrations.
29	Commissioned EVSEs	Number of V1G and V2G-capable charging points successfully installed and integrated at the test sites.
30	Smart Charging Tests Performed	Successful activation of V1G and V2G charging station, including its integration with the control systems for energy flow management.

8.1.5. Cybersecurity Assessment

These KPIs capture the assessment of cybersecurity robustness in the demonstrator, including identification of vulnerabilities, protocol-specific threats, and effectiveness of mitigation measures.

Table 8.5: Cybersecurity Assessment KPIs.

KPI	Name	Description
31	Effectiveness of Mitigations	Number and severity of attack scenarios that are successfully mitigated by implemented security measures, including those tested on OCPP 2.x..
32	Protocol-Specific Threats Identified	Number of unique threats or vulnerabilities identified and demonstrated during testing of OCPP-based communication, distinguishing between OCPP 1.6 and 2.x versions.
33	Endpoint Vulnerability Insights	Number and types of exploitable weaknesses identified on charging stations.

8.1.6. User and Stakeholder Engagement

These KPIs assess how users and stakeholders interact with and respond to the deployed technologies. They capture engagement levels, trust in AI-driven recommendations, usability of decision-support tools, and participation in smart charging services.

Table 8.6: User and Stakeholder Engagement KPIs.

KPI	Name	Description
34	Vessels charging	Number of real vessels using the charging system. At least one real vessel should be able to charge using the developed solution
35	Controllable charger utilization rate	Proportion of EV users who follow AI-recommended charging schedules.
36	Trust in AI solutions	Evaluates stakeholder acceptance of AI-generated recommendations. Measured as the ratio of accepted recommendations without major modifications to total recommendations provided.
37	Usability of decision support tools	Assesses how well the AI-based tools support decision-making. Measured through stakeholder ratings on clarity and usability.
38	Service participation rate	Percentage of EVs responding positively to the flexibility command

8.2. KPIs per Use Case

To ensure traceability and relevance of the performance indicators defined in the Western Europe demonstrator, we establish a mapping between the KPIs and the use case scenarios – see Table 8.7 (An “X” indicates that the corresponding KPI is applicable to the given scenario). This Scenario–KPI matrix provides a structured overview of which indicators apply to each scenario, helping to identify where specific measurements are required and supporting targeted analysis for evaluation and decision-making. The matrix also aids in ensuring coverage across technical, operational, and economic dimensions of the different use cases.

Table 8.7: Mapping between use cases and associated KPIs.

Location	Garage			Public Charging Infrastructure							Maritime-Touristic Area								Semi-Public Parking Lot						
SUC / KPI	2.3 S1	2.3 S2	2.3 S3	9.3 S1	9.3 S2	11.3 S1	11.3 S2	12.3 S1	12.3 S2	12.3 S3	4.2 S1	8.1 S1	8.2 S1	8.2 S2	8.3 S1	8.3 S2	2.3 S1	2.3 S2	3.3 S1	3.3 S2	4.1 S1	4.1 S2	5.1A S1	5.3A S1	5.3A S3
1	X	X	X				X						X	X	X	X	X	X					X	X	X
2							X							X		X		X					X		X
3	X	X	X				X						X	X	X	X	X	X					X	X	X
4	X	X	X				X						X	X	X	X	X	X					X	X	X
5	X	X	X				X					X	X	X	X	X	X	X					X	X	X
6	X				X		X				X						X	X			X	X			
7		X	X		X		X				X						X	X			X	X			
8	X	X	X		X		X				X						X	X			X	X			
9	X	X					X					X	X	X	X	X	X	X					X	X	X
10	X	X					X					X	X	X	X	X	X	X					X	X	X
11	X	X					X						X	X	X	X	X	X					X	X	X
12	X	X					X						X	X	X	X	X	X					X	X	X
13		X		X		X									X	X									
14		X	X				X						X	X	X	X		X					X	X	X
15		X	X				X					X	X	X	X	X		X					X	X	X
16		X	X				X					X	X	X	X	X		X					X	X	X

Location	Garage			Public Charging Infrastructure							Maritime-Touristic Area								Semi-Public Parking Lot						
SUC / KPI	2.3 S1	2.3 S2	2.3 S3	9.3 S1	9.3 S2	11.3 S1	11.3 S2	12.3 S1	12.3 S2	12.3 S3	4.2 S1	8.1 S1	8.2 S1	8.2 S2	8.3 S1	8.3 S2	2.3 S1	2.3 S2	3.3 S1	3.3 S2	4.1 S1	4.1 S2	5.1A S1	5.3A S1	5.3A S3
17				X				X																	
18									X																
19										X															
20																									
21	X	X	X				X						X	X	X	X	X	X					X	X	X
22		X	X				X								X	X	X	X					X	X	X
23	X	X	X				X	X				X	X	X	X	X	X	X					X	X	X
24														X		X		X					X		X
25														X		X		X					X		X
26														X		X		X					X		X
27																					X				
28	X					X					X						X								
29	X			X		X					X						X				X				
30	X	X	X	X			X				X						X				X	X			
31																			X	X					
32																			X	X					
33																			X	X					
34											X														
35	X	X					X										X	X					X		
36	X	X	X			X	X	X	X						X	X	X	X					X	X	X
37	X	X	X			X	X	X	X						X	X	X	X					X	X	X
38		X	X				X																X	X	X

9. CONCLUSION

9.1. Summary of Demonstrator Scope and Approach

This deliverable presented the final design of the Western Europe Demonstrator. The demonstrator focuses on studying EV charging across public, semi-public, and private infrastructures, with the overarching goal of testing AI-based control strategies and advanced hardware for coordinated EVSE management.

Two complementary locations in Portugal, Funchal (Madeira Island) and Lisbon, enable a diversified exploration of smart charging scenarios. In Funchal, the demonstration targets coordinated management across public and private infrastructure, reconciling the priorities of the Municipality, the DSO, and EV users. The setup includes three test sites: a Private Multi-Unit Residential Garage, a Public Charging Network, and a Touristic Port Area, which will explore maritime-touristic electrification and vessel charging. In Lisbon, the Semi-Public Parking Lot serves as a testbed for advanced parking management, on-site renewable integration, and cybersecurity testing – particularly of OCPP 2.x and innovative hardware such as the matrix-based charging pad.

9.2. Progress Achieved and Lessons Learned

Progress within Task 9.1 (Detailed Specification of the Demonstration Use Cases) can be grouped into three areas: 1) architectural design of the demonstration sites; 2) integration planning and computational platform definition; and 3) assessment methodology development.

- **Architectural Design:** Each demonstration site has been characterized in detail, covering infrastructure requirements, hardware selection (including EVSEs, smart meters such as Shelly Pro EM-50 and Pro 3EM), and innovative equipment like V2G chargers and the matrix-based charging pad. Use Case Scenarios (SUCs) have been mapped directly to each location, addressing topics from private smart charging (UC2) to cyber-secure operation (UC3) and maritime-touristic electrification (UC8).

- **Integration and Computational Platform:** A preliminary Data Integration Platform has been defined, detailing five core components: Data Sources, Data Source Interfaces (DSI), Data Storage, Control Modules, and External Applications. Key protocols, such as MQTT for unidirectional smart-meter data and OCPP for bidirectional EVSE communication, ensure standard-based interoperability.

- **Assessment Methodology:** To assess outcomes, a comprehensive KPI framework was defined and structured into six thematic areas: System Performance and Responsiveness, Decision and Control Performance, Economic and Environmental Impact, Technology Deployment and Validation, Cybersecurity Assessment, and User and Stakeholder Engagement. A Scenario–KPI matrix (Table 8.7) maps these indicators to specific use cases, ensuring traceability and clarity in the evaluation phase.

The activities carried out so far have provided valuable insights into the technical, organizational, and methodological aspects of implementing AI-based demonstrators, revealing several key lessons that will guide future phases.

- **Equipment and site identification challenges:** Selecting the correct hardware, particularly for emerging technologies such as matrix-based charging and V2G, required extensive market research and technical validation. Since these solutions are still under active development, their evolving specifications and limited commercial availability made planning and integration especially challenging. Similarly, identifying suitable locations for public charging infrastructure proved complex, as installations must comply with urban planning, safety, and regulatory requirements, highlighting the relevance and timeliness of the AHEAD tools, namely the AI-based planning solution, which can help anticipate such constraints.

- **Integration and interoperability challenges:** Early planning for the integration of AHEAD tools proved critical for ensuring consistency between planning, operation, and cybersecurity layers. However, early testing also revealed interoperability nuances in existing standards. For example, while the OCPP protocol defines a common standard, variations across manufacturers in how commands and data are structured will require additional handling mechanisms at the computational layer to ensure interoperability.

- **KPI complexity and mapping effort:** The extensive number of KPIs and use cases required a careful process of categorization and mapping. This exercise was critical to ensure that each KPI could be meaningfully applied and measured across diverse demonstration scenarios, while avoiding redundancy and ensuring comparability.

9.3. Potential Challenges and Mitigation Measures

9.3.1. Preparatory Measures under the New Electric Mobility Regime

The recent regulatory changes in Portugal, introduced through Decreto-Lei n.º 93/2025, establish ad hoc payments, transparent pricing, and increased competition in public charging networks. The regulatory changes primarily affect the public charging infrastructure in Funchal.

These rules will come into full effect after January 2027, while WED) runs until May 2028. However, thanks to the demonstration design and the fact that the consortium benefits from key stakeholders: EMACOM, a major CPO managing the AHEAD chargers; MOBIE, providing visibility to the charging infrastructure, and CMF that owns most of the public charging infrastructure in the public charging demonstrator, these changes are not expected to significantly disrupt ongoing activities.

Nevertheless, the consortium is proactively preparing for potential challenges. Multiple EVSE brands are being tested to address interoperability and implementation variations, supported by a highly flexible computational backend capable of accommodating differences in protocols and operational behaviors. Furthermore, engagement with end users—who are the primary beneficiaries of these regulatory changes and will enjoy greater flexibility in charging—will be carried out to capture their perceptions, motivations, and practical challenges. This ensures that the demonstrator not only validates technological and operational solutions but also provides actionable insights into user experiences under evolving public charging policies.

9.3.2. Municipal Policy and Election Considerations

While the Funchal City Hall (CMF) is an active consortium partner and owner of the public charging infrastructure included in the demonstrator, potential changes in municipal leadership, such as following local elections, could influence mobility priorities or operational rules. For example, while policy alignment is ensured with Decreto-Lei n.º 93/2025, a new administration may introduce complementary municipal policies (e.g., preferential tariffs, local mobility programs) that could influence how EV drivers interact with the infrastructure. Shifts in deployment priorities are also possible: a new head of mobility may wish to emphasize different locations, reallocate public EVSE, or modify incentives for adoption.

To mitigate these risks, the project emphasizes flexible planning of EVSE deployment and computational backends, enabling adjustments in locations or operational procedures without affecting demonstration outcomes. Continuous stakeholder engagement with municipal staff ensures alignment on objectives, while thorough documentation of procedures safeguards the continuity of approvals, workflows, and operational practices throughout the demonstration period.

9.4. Upcoming Steps and Deliverables

In the next phase of the Western Europe Demonstrator, the consortium will focus on deploying and integrating the remaining EVSE across the demonstration sites, including both private and public infrastructures. Key activities include testing hardware innovations such as V2G and matrix-based chargers and implementing AI-based planning and operational tools.

End-user engagement campaigns will be conducted to gather insights on perceptions, motivations, and operational challenges across diverse user groups, including private garage owners, users of public charging infrastructure, maritime-touristic operators, and users of the semi-public parking lot in Lisbon.

The next deliverable for the Western Europe Demonstrator is the development of the Maritime-Touristic area Digital Twin (D9.2 due on M21), a software-based tool designed to simulate and optimize maritime-touristic electrification at the Funchal Port. The Port Digital Twin will provide a comprehensive simulation environment, including data-driven route generation based on marine traffic patterns, vessel simulation incorporating specific vessel characteristics, simulation of vessel charging integrated with the electrical network, and PV generation simulations. It will support real-time and offline simulations based on planned vessel schedules, and will be implemented in open-source Python, featuring a user interface and optimization mechanisms for operational planning.

The subsequent deliverable will focus on the Installation, Commissioning, and Integration of the Western Europe Demonstrator (D9.3, due on M24). It will provide a detailed account of the preparations for the site, presenting the implementation of technical and technological infrastructures, including EVSE deployment, smart meters, novel charging hardware, and computational platforms. This report will document how the demonstrator is physically and digitally integrated to support the planned use cases across all demonstration locations.

REFERENCES

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