



AI-informed Holistic Electric Vehicles Integration Approaches for Distribution Grids

D1.4

Scenario and Use Case Formulation

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EXECUTIVE SUMMARY

This deliverable, D1.4 – Scenario and Use Case Formulation, provides a structured definition and description of the scenarios and use cases that will be developed and demonstrated within the AHEAD project. It defines the high-level requirements and specifications for the early stage of project development and serves as a foundation for the demonstration work packages (WPs 7–9). The main objective is to identify and describe the scenarios and use cases to be tested in the demonstrators, ensuring alignment with AHEAD’s overall goals.

The report introduces the demonstration sites in Nordic, Southern, and Western Europe, outlining their infrastructures and planned implementations. Each site is linked to a specific set of use cases that will be deployed and validated in real operational environments. These testbeds will ensure that the solutions are evaluated under diverse geographical, regulatory, and operational conditions, providing a robust basis for assessing their feasibility and scalability.

Use case definition has been carried out with contributions from relevant stakeholders, including vehicle owners and operators, energy providers, system operators, and regulatory authorities, who will also play a key role in subsequent development and validation phases. The work includes an assessment of the technical, economic, and regulatory feasibility of the proposed solutions, considering both short-term deployment and long-term sustainability.

The deliverable applies the IEC 62559-2 Use Case Methodology as a standardized framework, which guarantees consistency, interoperability, and reusability of the defined use cases across partners and beyond the project scope. In total, twelve use cases have been defined. For each one, the document provides:

- scope and objectives,
- a complete High-Level Use Case description,
- decomposition into Primary Use Cases and Specialized Use Cases,
- associated key performance indicators,
- actor interactions,
- requirements, and
- scenario descriptions.

LIST OF ACRONYMS

AC	Alternate Current
AFIR	Alternative Fuels Infrastructure Regulation
AI	Artificial Intelligence
BEB	Battery Electric Bus
BESS	Battery Energy Storage System
CPO	Charging Point Operator
DC	Direct Current
DER	Distributed Energy Resources
DR	Demand Response
DSO	Distributed System Operator
EMS	Energy Management System
EV	Electric Vehicle
EVSE	Electric Vehicle Supply Equipment
GDPR	General Data Protection Regulation
GIS	Geographic Information System
GPS	Global Positioning System
HDV	Heavy-Duty Vehicle
HIL	Hardware-in-the-Loop
HLUC	High-Level Use Case
HV	High Voltage
IEC	International Electrotechnical Commission
KPI	Key Performance Indicators
LV	Low Voltage
MV	Medium Voltage
O&M	Operation and Maintenance
OCPP	Open Charge Point Protocol
PTO	Public Transport Operator
PUC	Primary Use Case
PV	Photovoltaic
RES	Renewable Energy System
SCADA	Supervisory Control and Data Acquisition
SOC	State of Charge
SPD	Shore Power Pedestal
SUC	Specialized Use Case
THD	Total Harmonic Distortion
TSO	Transmission System Operator
UC	Use Case
V1G	Vehicle-one-Grid
V2G	Vehicle-to-Grid
VPP	Virtual Power Plant
WP	Work Package

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1. INTRODUCTION

1.1. Context

Deliverable D1.4 – Scenario and Use Case Formulation documents the work completed in Task 1.4. The main objective of this task is to define the scenarios and use cases (UCs) that will be tested and validated in the AHEAD demonstrators (WPs 7–9). These scenarios cover a wide range of applications, including urban mobility, long-distance logistics, and maritime transport, and are designed to contribute directly to the achievement of the project objectives.

Use case formulation has been developed in close collaboration with key stakeholders, such as vehicle owners and operators, energy providers, distribution and transmission system operators, and regulatory bodies. This participatory approach ensures that the proposed solutions are aligned with technical, operational, market, and regulatory requirements. In parallel, the work has assessed the technical, economic, and regulatory feasibility of the use cases, with a view to both near-term implementation and long-term sustainability.

To provide a comprehensive overview, the twelve use cases defined at proposal stage and further detailed within this deliverable are summarized in Figure 1. The figure illustrates their scope, objectives, and allocation across the three demonstration regions (Nordic, Southern, and Western Europe). Together, they reflect the diversity of applications addressed in the project, ranging from smart charging strategies to flexibility services and artificial intelligence (AI)-based planning tools.

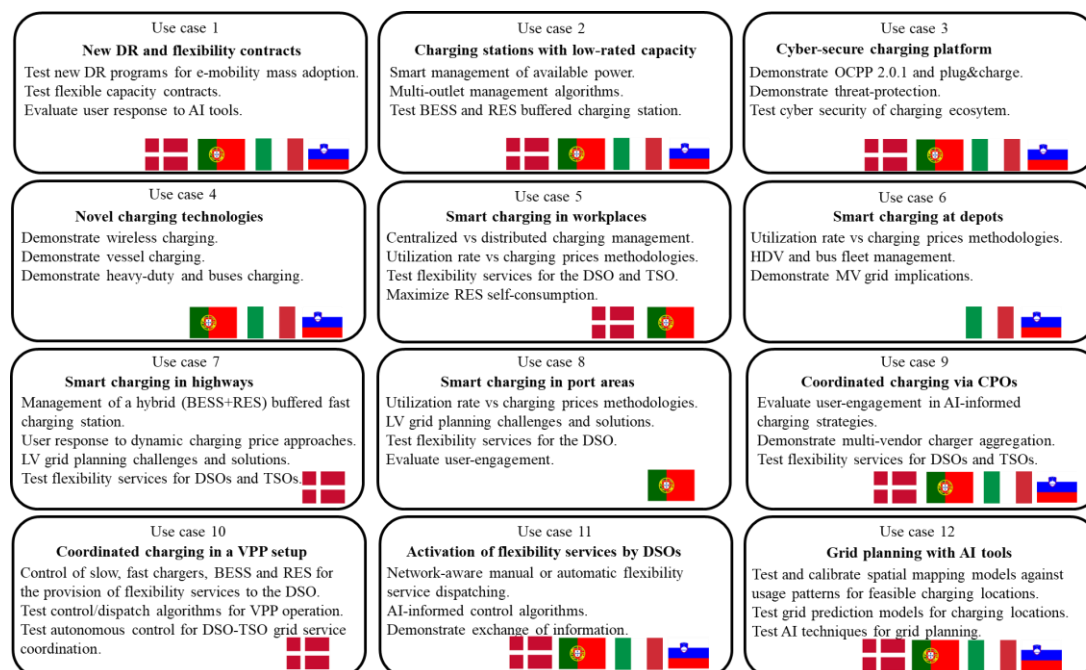


Figure 1 – Overview of AHEAD use cases and their deployment across demonstration sites.

The deliverable pursues four main objectives:

- 1) Define and apply a methodology for the systematic description of use cases, based on the International Electrotechnical Commission (IEC) standard IEC 62559-2 [1].
- 2) Establish a comprehensive list of use cases for the AHEAD project.
- 3) Describe the characteristics, objectives, requirements, key performance indicators (KPIs), and actor interactions of each use case.
- 4) Link the use cases to the demonstration sites where they will be implemented and validated.

The demonstration activities in Nordic, Southern, and Western Europe cover diverse geographical, technical, and regulatory contexts. Each site hosts pilots addressing complementary aspects of electric mobility and grid integration, such as combined service delivery at multi-vendor charging hubs, fleet and heavy-duty vehicle charging depots, and AI-enabled planning and cyber-secure charging platforms. These real-world testbeds provide a robust foundation to validate the proposed use cases under varied conditions, ensuring that the results of AHEAD are scalable, replicable, and impactful at the European level.

1.2. Document structure

This deliverable is organized as follows:

- **Chapter 2** introduces the use case methodology, based on IEC 62559-2, and presents the key concepts used throughout the document.
- **Chapter 3** provides an overview of the three demonstration sites in Nordic, Southern, and Western Europe, describing their infrastructures, actors, and technical requirements for use case implementation.
- **Chapter 4** presents the use cases, including their scope and objectives. Use cases are specified at different levels of granularity and abstraction:
 - *High-Level Use Cases (HLUCs)* provide the general concept and overall idea.
 - *Primary Use Cases (PUCs)* focus on the detailed description of specific functionalities, features, or processes.
 - *Specialized Use Cases (SUCs)* describe the implementation of use cases in the context of a particular demonstration site.

In addition, each use case includes feasibility considerations from technical, economic, and regulatory perspectives.

- **Annex I** provides the IEC 62559-2 template adopted within the AHEAD project together with the complete UC tables, ensuring traceability and methodological consistency. The same material is also maintained in the AHEAD GitHub repository: <https://github.com/AHEAD-EU/use-cases>.

1.3. Relationship with other deliverables

The work presented in this deliverable provides the consortium and stakeholders with an overview of the activities and tools to be developed throughout the project, thereby supporting the achievement of AHEAD's objectives. It is directly linked to the demonstration work packages (WPs 7–9) and their respective tasks, as it defines the scenarios and use cases that will be implemented and validated within the demonstration sites.

In this deliverable, the High-Level and Primary Use Cases are fully described, and initial details of the Specialized Use Cases are also provided to give a complete overview of their scope and relevance for the AHEAD demonstrations. The level of detail currently provided for the SUCs may vary across demonstration sites, reflecting the different maturity levels, implementation timelines, and currently available technical information for the corresponding pilots. Accordingly, some SUCs are currently described only at a high level, while others already include more detailed technical and operational information. These specifications will be further expanded in the following deliverables:

- D7.1 and D7.2 of WP7 – *Combined service delivery from heterogeneous charging stations (Nordic Europe Demo)*.
- D8.1 and D8.2 of WP8 – *AI-based planning tool and flexibility services from HDVs, fleets, and public transportation (Southern Europe Demo)*.
- D9.1 of WP9 – *AI tools for the seamless integration and coordination of public and private charging infrastructures (Western Europe Demo)*.

2. USE CASE METHODOLOGY

2.1. IEC 62559-2

The International Electrotechnical Commission (IEC) has established an international standard methodology for the definition and description of use cases, formalized in the IEC 62559-2 standard, entitled *Use Case Methodology – Definition of the templates for use cases*,

actor list and requirements list [1]. The IEC is a globally recognized organization that fosters cooperation in the field of standardization within the electrical and electronic domains. The IEC 62559-2 standard specifies the fundamental concepts and terminology forming the basis of UC development, thereby enabling the creation of a shared repository of UCs, while also providing a comprehensive template that defines the essential structure of a UC and a method for its serialization.

This standard was originally conceived with projects in the electrical and electronic sectors and its adoption in AHEAD project represents a natural alignment. The IEC 62559-2 standard constitutes an appropriate reference framework for AHEAD, serving as the basis for the definition of its use cases. By employing the IEC template, AHEAD will systematically define the set of scenarios to be developed in the demonstrators activities, identifying the functionalities that will be implemented and tested.

The resulting AHEAD use case template is structured into five principal sections, which may be summarized as follows:

1. *Description of Use Case* – this section delineates the scope, objectives, key performance indicators, assumptions and preconditions associated to each AHEAD UC.
2. *Diagram of Use Case* – this section provides a visual representation of the relationships between a given UC, other UCs within the project, and the corresponding actors.
3. *Technical details* – this section identifies the actors associated with each UC and specifies their respective roles.
4. *Step by step analysis of Use Case* – this section provides the description of the different scenarios of the use case using a step-by-step analysis, including the interactions, processes, and functionalities tested within the demonstration activities.
5. *Information Exchanged* – the final section specifies the data flows required to be exchanged between actors or across UCs.

The complete version of the IEC 62559-2 use case template [1], adopted within the AHEAD project, is provided in Annex I – *Description of the Use Case Template*.

2.2. Key concepts

This section provides the key terminology related to the UCs referenced throughout this report, following the definitions established in the IEC standard. In order to correctly understand and

complete the UC template, it is crucial to rely on clear definitions of the main concepts. From the wide set of definitions available in the IEC standard, the most relevant ones have been selected: Actor, Domain, Scenario, Primary Use Case and Specialized Use Case.

- **Actor:** any entity that communicates and interacts in the UC. Actors may include people, software applications, systems, databases, or even the power grid itself (e.g., aggregators, distribution system operators or transmission system operators).
- **Domain:** a field of knowledge or activity that employs a set of concepts and terminology commonly understood by specialists in that area.
- **Scenario:** a possible sequence of interactions, described step by step, with the relevant data exchanges clearly specified.
- **Primary Use Case:** a UC that gives a detailed description of particular functionalities, features, or solutions, PUCs are usually tied to a goal or system requirement providing a detailed and context specific information.
- **Specialized Use Case:** a UC that uses a specific technological solutions defined in the primary use case, considering the particular demonstration location. The SUC specifies how the functionalities described in the PUC are implemented and tested in the specific demo sites.

3. DEMONSTRATION SITES OVERVIEW

The AHEAD project includes demonstration activities across Nordic, Southern, and Western Europe. Each demonstration site addresses a different combination of HLUCs, reflecting the diversity of charging infrastructures, operational conditions, flexibility services, and innovative technologies investigated within the project.

3.1. Nordic Europe demo

The Nordic Europe demonstrator includes two sites in Denmark: Location 1 in the Danish countryside, and Location 2 on the DTU-Risø campus. An overview of the demonstrator is shown in Figure 2.

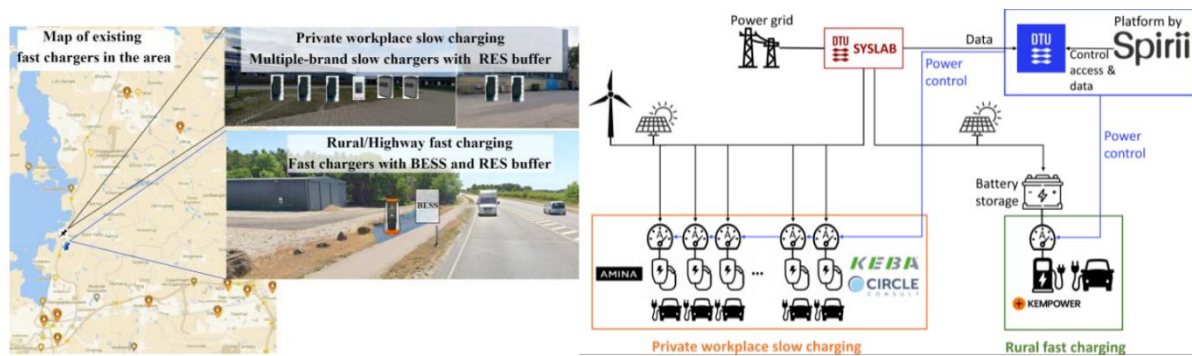


Figure 2 – Demonstration locations for the Nordic site.

Location 1, also referred to as the “Fast charging demo”, is located in the Danish countryside and allows all users to utilise the newly installed fast-charging infrastructure supplied by KEMPOWER (operated commercially by SPIRII), consisting of one 150 kW DC fast charger with two plugs. The HLUCs addressed at this location are summarized in Table 1.

Location 2, also referred to as the “Slow charging demo”, is located within the DTU-Risø campus, adjacent to office buildings, and provides approximately 500 employees, visitors, and students with access to a newly installed slow-charging infrastructure supplied by AMINA and operated commercially by SPIRII. The site currently includes nine AC charging points from different manufacturers (AMINA, Zaptec, and Fronius). The total grid capacity initially required by the chargers amounts to 132 kW; however, a smart charging strategy will be implemented to accommodate the large number of chargers with only 43 kW of grid capacity (32% of the initial capacity request). The chargers employ a distributed control approach, offering greater capabilities and resilience than mass-market products that rely on a single, cloud-based (centralised) controller, which represents a single point of failure. This environment enables the design and testing of solutions to techno-economic and societal challenges associated with deploying large-scale AC charging infrastructure. The HLUCs addressed at this location are summarized in Table 1.

In addition, both locations offer the possibility to couple charging demand with local photovoltaic (PV) generation (30 kW), wind generation (22 kW), and a Pixii battery energy storage system (BESS) (325 kWh/150 kW). This configuration resembles future charging hubs and reduces the required grid connection capacity. In fact, despite the reduced grid capacity (43 kW available), the expected charging needs can still be satisfied.

Table 1 – Mapping of HLUCs to the Southern Europe demonstration sites.

Location	HLUC	Title
Location 1 – Fast charging demo	HLUC1	New demand response and flexibility contracts
	HLUC2	Charging stations with low-rated capacity
	HLUC3	Cyber-secure charging platform
	HLUC7	Smart charging in highways
	HLUC9	Coordinated charging via charge point operators
	HLUC10	Coordinated charging in a virtual power plant setup
	HLUC11	Activation of flexibility services by distribution system operators
Location 2 – Slow charging demo	HLUC12	Grid planning with artificial intelligence tools
	HLUC1	New demand response and flexibility contracts
	HLUC2	Charging stations with low-rated capacity
	HLUC3	Cyber-secure charging platform
	HLUC5	Smart charging in workplaces
	HLUC9	Coordinated charging via charge point operators
	HLUC10	Coordinated charging in a virtual power plant setup
	HLUC11	Activation of flexibility services by distribution system operators
	HLUC12	Grid planning with artificial intelligence tools

3.1.1. Actors

The Nordic Europe demonstrator brings together electric vehicle (EV) users, site owners, charge point operators (CPOs), grid operators, and technology partners across two complementary locations, a rural highway fast-charging hub (Location 1) and a multi-vendor workplace charging campus at DTU-Risø (Location 2), to validate smart charging, flexibility, and secure, interoperable operations under tight grid-capacity constraints.

Location 1 brings together public EV users, the technology provider, and the commercial CPO to operate a fast-charging site. The CPO authorises sessions, applies tariffs, and exposes open charge point protocol (OCPP) back-end interfaces consumed by the site energy management system (EMS) to execute set-points. The EMS coordinates grid import, BESS charge/discharge, and PV utilisation to respect feeder limits while maintaining quality of service for drivers. The local distribution system operator (DSO) defines the connection agreement, supervises compliance with feeder/transformer limits, and can issue flexibility or curtailment requests during network stress. Where system conditions warrant, the transmission system operator (TSO), via the DSO, may signal system-level events that the site can respond to through coordinated EMS/CPO control.

Location 2 (DTU-Risø campus) brings together EV users, the site owner, and the CPO across a heterogeneous slow-charging fleet. The EMS, integrating distributed control where supported optimises scheduling for self-consumption, peak shaving, and user service levels.

The DSO sets grid constraints and, together with the TSO where applicable, can trigger demand-response events that the EMS and CPO execute and log for verification. The campus SYSLAB provides measurement, distributed energy resources (DER) integration, and virtual power plant (VPP)-oriented control/dispatch capabilities to test coordinated charging and flexibility.

Across both locations, cybersecurity specialists conduct targeted assessments focused on station/back-end hardening and secure communications (OCPP 1.6/2.x), validating mitigations against realistic threat scenarios. Moreover, planners, site owners, the CPO, and the DSO contribute geographic information system (GIS) layers, connection rules, telemetry, and usage datasets to the project's AI-based planning tools, spatial grid models, and hosting-capacity analysis tools, which return suitability and hosting-capacity insights to guide siting, upgrades, and phased deployment of workplace and roadside fast-charging hubs.

3.1.2. Components and technical requirements

The Nordic demonstrator combines a newly deployed, SPIRII-operated KEMPOWER fast-charging site in the Danish countryside and a newly deployed, SPIRII-operated multi-brand slow-charging site at DTU-Risø, each coupled with local DERs and smart control. Technical requirements cover multi-vendor interoperability via OCPP, secure telemetry at site/charger level, per-outlet or bank power-cap enforcement, and the use of local DER signals to optimize operation.

3.2. Southern Europe demo

The Southern Europe demonstrator includes two sites: Location 1 in Milan, Italy, and Location 2 in Kranj, Slovenia. An overview of the demonstrator is shown in Figure 3.

In Location 1 (Milan), the test site is the parking area of a high voltage/medium voltage (HV/MV) primary substation in Milan. It hosts both fast and slow EV charging for the operations and maintenance (O&M) fleet and corporate car sharing. The site currently includes 37 twin-socket AC charging stations: 27 single-phase 3.6 kW units and 10 wallboxes, of which 8 are single-phase 3.6 kW and 2 are three-phase 22 kW. The installation operates at standard AC 230/400 V levels; connectors are AC type (wallbox/twin-socket). The HLUCs addressed at this location are summarized in Table 2.

In Location 2 (Kranj), the demonstration is centred on the Primskovo district of Kranj, a few hundred metres from Elektro Gorenjska's headquarters and supplied directly from the adjacent 110/20 kV Primskovo primary substation. The existing pilot footprint comprises two OppCharge pantograph stations, each with twin outlets (four charging points total). Every

outlet is rated at 150 kW, enabling high-power fast charging for electric-bus operations, so the site can currently deliver up to 300 kW ($\approx 5 \text{ MWh day}^{-1}$) to the electric-bus fleet. Incoming power is taken at 20 kV (MV), stepped down to 400 V AC, and converted internally to 450–850 V DC at the charger, ensuring compatibility with today's pantograph-equipped buses. Over the coming years, the site will be expanded into a multi-modal heavy-duty-vehicle (HDV) depot with a reserved grid capacity of 20 MW, spanning the 110/20 kV primary substation and the 20 kV MV network. The expansion plan adds 24 $\times$ 400 kW CCS2 dispensers for trucks and coaches, six 450 kW pantographs for high-floor buses, and four megawatt charging system stands capable of 1.2–3 MW each. A 450 kW/900 kWh stationary battery will provide peak shaving and bidirectional vehicle-to-grid (V2G) support, allowing the depot to act as a flexibility node. All assets will be simulated within the AHEAD platform, which couples grid models with control algorithms to schedule smart charging, deliver demand-response services, and defer grid reinforcements. The HLUCs addressed at this location are summarized in Table 2.

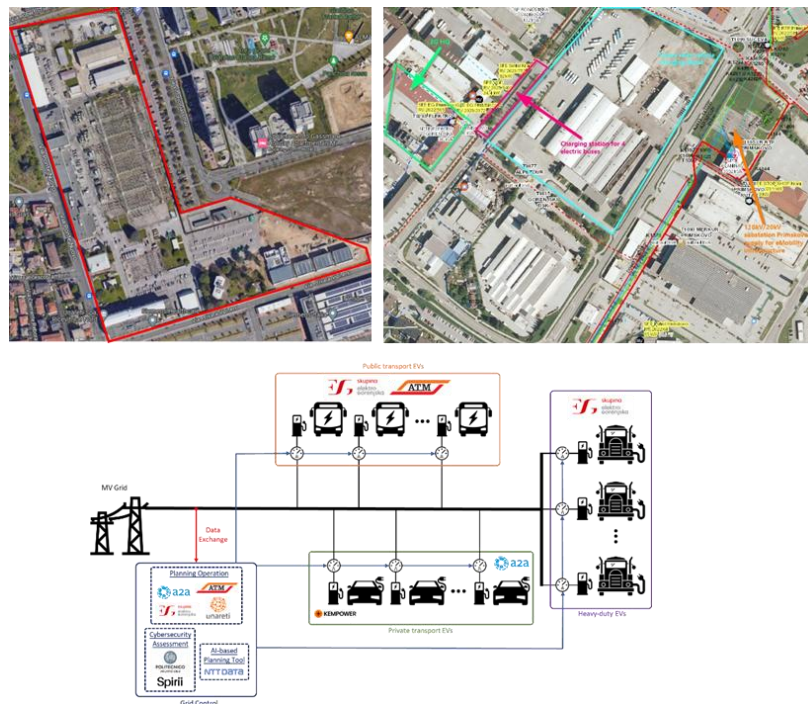


Figure 3 – Demonstration locations for the Southern Europe Demo.

Table 2 – Mapping of HLUCs to the Southern Europe demonstration sites.

Location	HLUC	Title
Location 1 – Milan demo	HLUC1	New demand response and flexibility contracts
	HLUC2	Charging stations with low-rated capacity
	HLUC3	Cyber-secure charging platform
	HLUC4	Novel charging technologies
	HLUC6	Smart charging at depots
	HLUC9	Coordinated charging via charge point operators

Location 2 – Kranj demo	HLUC11	Activation of flexibility services by distribution system operators
	HLUC12	Grid planning with artificial intelligence tools
	HLUC1	New demand response and flexibility contracts
	HLUC2	Charging stations with low-rated capacity
	HLUC3	Cyber-secure charging platform
	HLUC4	Novel charging technologies
	HLUC6	Smart charging at depots
	HLUC9	Coordinated charging via charge point operators
	HLUC11	Activation of flexibility services by distribution system operators
	HLUC12	Grid planning with artificial intelligence tools

3.2.1. Actors

The Southern Europe demonstrator brings together a tight coalition of grid stakeholders, fleet operators, site owners, and technology providers, aligned around one active depot in Milan (Location 1) and one planning-and-simulation site in Kranj (Location 2).

Location 1 (Milan) brings together the public transport/fleet operator and the site owner/CPO to run day-to-day depot operations and expose real duty-cycle data, state-of-charge (SOC)/departure constraints, and service-level needs. The DSO sets connection limits and export permissions and can trigger flexibility/V2G events; the new V2G charger and the charging/depot management system enforce optimised, bidirectional profiles within those limits. Cybersecurity specialists conduct targeted assessments, covering station/back-end hardening and secure communications (e.g., OCPP 1.6/2.x), to validate mitigations under realistic workflows.

Location 2 (Kranj) is led by the local DSO (Elektro Gorenjska), which provides grid-side interfaces, SCADA (supervisory control and data acquisition) data, and operational constraints, acting as the site-integration lead. The fleet operator supplies depot access, operating schedules, and fleet requirements, while technology partners deliver charger hardware/software, data acquisition, forecasting, and optimisation services for a mixed-fleet charging park. Operations are managed by the EMS: it processes grid limits and fleet needs, tests dispatch logic under realistic constraints, and returns results to the DSO to refine congestion-management procedures.

In addition, across both locations, planners, CPOs, and the DSO provide GIS layers, connection rules, and depot-usage datasets to the project's AI planning tool, which returns suitability and hosting-capacity insights to guide siting, upgrades, and phased deployment.

3.2.2. Components and technical requirements

The Southern demonstrator foresees targeted upgrades and integrations across two locations, combining real-world assets with simulation-driven testing and analysis.

In Location 1 (Milan), a new 100 kW V2G charging station will be deployed adjacent to the secondary cabin designated for the charging infrastructure. The system will include a power unit and a charging terminal (configured as either a satellite unit or a control unit), along with the required civil and electrical works, protection and metering, and connectivity to the local network. The site offers sufficient space for the charger installation, parking of buses, and the placement of a battery used for simulation and testing. Technical requirements cover bidirectional power control and telemetry, integration with the site's supervisory/control layer, secure remote monitoring, and standardized interfaces for real-time command, logging, and participation in flexibility tests.

In Location 2 (Kranj), activities will focus mainly on simulation and analysis, with limited real-time activations to test the use cases. Simulation tools integrated with SCADA measurements will be developed, meaning the requirements concern primarily interoperability and standardization of communication between real devices and the simulation environment. The same processes and communication channels that will be used once deployable assets are on site will already be adopted here, and the site will also provide network-wide information to support planning use cases.

3.3. Western Europe demo

The Western Europe demo focuses on EV charging across public and private infrastructures. Three pilots will be implemented in two locations in Portugal: Funchal (Location 1) and Lisbon (Location 2). An overview of the demonstrator is shown in Figure 4 and Figure 5. To support the coordination, monitoring, and integration of the different pilots and charging infrastructures, the Western Europe demonstrator relies on the birdsEView platform, a modular data integration and control platform developed within AHEAD. The platform aggregates data from EVSEs (electric vehicle supply equipment), smart meters, simulation services, and external systems, while also supporting operational planning, real-time control, dashboards, and stakeholder-oriented applications

The Funchal demonstration will concentrate on: (1) grid-level planning, assessing the impact of growing private and public EVSE demand on a geographically isolated grid; and (2) city-level planning, delivering a public charging infrastructure adequate for city management, including port-related needs.

The Lisbon demonstration will focus on two main aspects: (1) parking-lot operations and energy management in semi-public settings under rising EVSE demand, covering smart scheduling, integration with local DERs, grid observability, and participation in flexibility services; and (2) technology validation, assessing advanced charging solutions (e.g., bidirectional EVSEs and matrix-based charging) within the existing management and control architecture.

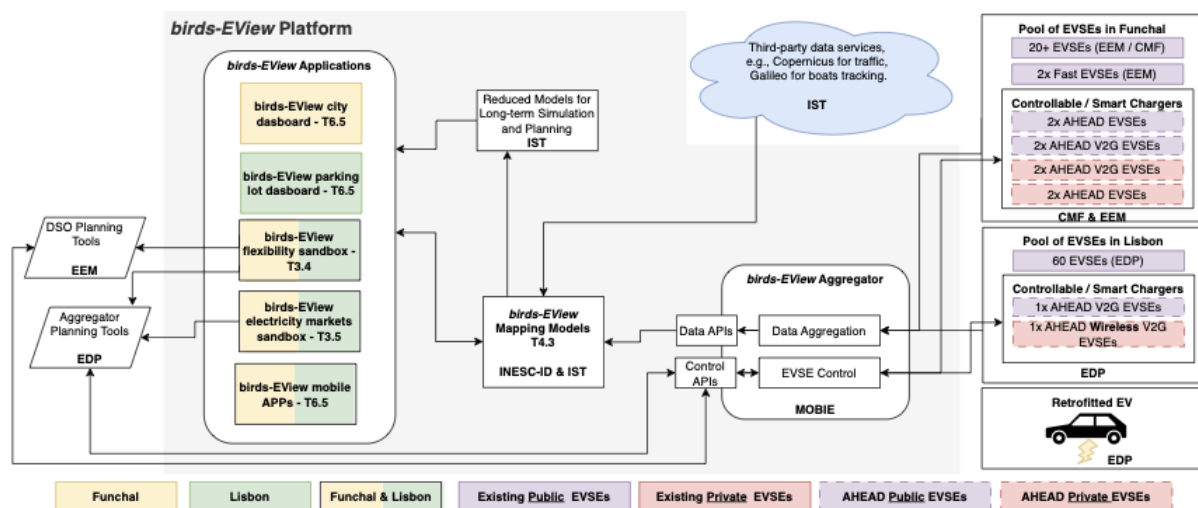


Figure 4 – Overview of the Western Europe Demo infrastructures and tools.



Figure 5 – Parking lot infrastructure in EDP installations.

3.3.1. Location 1 – Pilot 1: Residential building with a common parking area

The activities in Pilot 1 demonstrate coordinated control of EVSE in residential buildings with shared parking areas. This coordination enables multiple smart-charging schemes that deliver services to both EV owners and the DSO. For EV owners, a key benefit is the ability to charge several vehicles simultaneously without increasing the building contracted power. For the DSO, services include explicit demand response, whereby the operator can request control of the garage EVSE. The HLUCs addressed at this location are summarized in Table 3.

3.3.2. Location 1 – Pilot 2: Funchal Downtown

Pilot 2 aims are to demonstrate the management of public EVSEs infrastructure considering the needs of two key stakeholders: 1) the municipality that needs to provide a public charging infrastructure; and 2) the DSO that needs to guarantee the quality of the electricity supply. The pilot will operate across two sub-sites, one covering the public charging network across the city and the other the touristic port area. Given the specific geographical context of the city, where the port is situated in the city downtown, this arrangement is feasible for experimentation with the charging of electric/hybrid boats already existing in the port. The overarching objective of this initiative is to construct a digital twin of the maritime-tourism area in the Port of Madeira, i.e., a dynamic digital representation continuously fed with real and simulated data to support monitoring, simulation, and decision-making processes. The HLUCs addressed at this location are summarized in Table 3.

3.3.3. Location 2 – Pilot 3: EDP Parking Lot

The demonstration in Lisbon will address challenges and opportunities arising from increased demand for EVSE in parking facilities. Activities will focus on developing parking-management strategies that account for EV needs, site power consumption, on-site PV generation, and participation in flexibility services. In addition, the demo will assess the technical feasibility of integrating and operating bidirectional, matrix-based AC chargers within the parking lot. The HLUCs addressed at this location are summarized in Table 3.

Table 3 – Mapping of HLUCs to the Western Europe demonstration sites.

Location	HLUC	Title
Location 1 – Pilot 1: Residential building with a common parking area	HLUC1	New demand response and flexibility contracts
	HLUC2	Charging stations with low-rated capacity
	HLUC9	Coordinated charging via charge point operators
	HLUC11	Activation of flexibility services by distribution system operators
	HLUC12	Grid planning with artificial intelligence tools
Location 1 – Pilot 2: Funchal demo	HLUC1	New demand response and flexibility contracts
	HLUC4	Novel charging technologies
	HLUC8	Smart charging in port areas
	HLUC9	Coordinated charging via charge point operators
	HLUC11	Activation of flexibility services by distribution system operators
Location 2 – Pilot 3: EDP Parking demo	HLUC12	Grid planning with artificial intelligence tools
	HLUC1	New demand response and flexibility contracts
	HLUC2	Charging stations with low-rated capacity
	HLUC3	Cyber-secure charging platform
	HLUC4	Novel charging technologies
	HLUC5	Smart charging in workplaces
	HLUC9	Coordinated charging via charge point operators

	HLUC11	Activation of flexibility services by distribution system operators
	HLUC12	Grid planning with artificial intelligence tools

3.3.4. Actors

The Western Europe demonstrator brings together a compact but complete ecosystem of public asset owners, grid stakeholders, operators, users, and technology providers, aligned with two pilots in Funchal (Location 1) and one in Lisbon (Location 2).

Location 1, Pilot 1 (Residential Building, Funchal) involves EV owners and the condominium/building manager, who enable coordinated unidirectional smart charging (vehicle-one-grid (V1G)) and bidirectional V2G charging and provide preferences and constraints to EMS. The DSO supervises local network limits, issues explicit demand-response requests, and supports data access and integration with existing assets. Chargers/CPO back-end providers expose OCPP interfaces used by the EMS to execute schedules.

Location 1, Pilot 2 (Funchal Downtown/Port), covers downtown/port activities, where actors include the Municipality of Funchal (public-realm owner and city-charging policymaker), the Port Authority, maritime operators/vessel companies (hybrid/electric vessels and timetables), and the DSO. For the city-wide public charging network, the Municipality and DSO align deployment with city objectives (accessibility, equity, efficient use of shared resources) while addressing grid concerns (congestion, peak load, voltage stability). For the touristic port area, the DSO remains the system-balancing authority and, where relevant, coordinates with the TSO for frequency services; vessel operators interact via dedicated dashboards/apps so charging plans respect trip schedules and operational windows, and infrastructure enhancements enable advanced simulations via a digital twin of the port.

In Location 2, Pilot 3 (EDP Parking Lot, Lisbon), EDP acts as site owner and technology integrator for a large semi-public installation. Fleet managers/drivers provide real duty cycles and service-level needs; the parking-lot EMS and AI scheduling components orchestrate power sharing, PV/BESS usage, and participation in flexibility events. Third-party CPO platforms operate most sockets, while a subset of fully controllable chargers is dispatched directly by project algorithms. Cybersecurity experts assess threats and mitigations on OCPP 1.6/2.x.

In addition, across both locations, planners, CPOs, and the DSO provide GIS layers, connection rules, and vessel- and parking-usage datasets to the project's AI planning tool, which returns suitability and hosting-capacity insights to guide siting, upgrades, and phased deployment of city, port, and semi-public charging.

3.3.5. Components and technical requirements

The Western Europe demonstrator foresees the deployment of new EVSEs in the two locations, as well as the integration with existing infrastructure.

In Location 1, it will be necessary to install different types of EVSEs, ranging from simple OCPP enabled sockets to full-fledged V2G chargers. V1G chargers, including sockets, will be installed in the private garage and in the port area (via retrofitting of an existing shore power pedestal (SPD)). V1G chargers will also be deployed in the city of Funchal, in locations selected by the Municipality. V2G chargers are also expected to be installed in a public parking lot managed by the Funchal municipality. All these chargers will be fully accessible and controllable by the AHEAD team. In terms of existing infrastructure, through the Mobi.E infrastructure (the Portuguese national electric mobility network), it will be possible have a near real-time view of the status, e.g., “available”, “charging”, “out of order” of the public charging infrastructure in Funchal. Furthermore, Empresa de Electricidade de Madeira will facilitate the full integration and control by the AHEAD team of two fast chargers that are also publicly available on the premisses of their headquarters.

In Location 2, there are already over 60 EVSEs that will be integrated in the AHEAD project via the EDP facilities. This charging infrastructure will be complemented with the installation and integration of one for V2G charger and one matrix-based charger. To enable the demonstration of the matrix-based charger, and EV from the EDP’s fleet will have to be retrofitted during the project.

4. USE CASE DESCRIPTION

This section presents the High-Level Use Cases defined within the AHEAD project, together with a concise description of their scope, objectives, mapping to Primary and Specialized UCs, and an assessment of their technical, economic, and regulatory feasibility.

The HLUCs cover a broad range of topics related to EV charging infrastructure, smart and coordinated charging, flexibility services, cybersecurity, AI-based planning, grid integration, and innovative charging technologies across the different AHEAD demonstration sites. The descriptions provided in this section are intentionally abridged to maintain readability and provide a high-level overview of the scenarios and functionalities to be demonstrated within the project.

Annex I provides the IEC 62559-2 template adopted in AHEAD together with the complete UC tables, which are also available in the AHEAD project’s GitHub repository: <https://github.com/AHEAD-EU/use-cases>.

4.1. HLUC1 – New demand response and flexibility contracts

4.1.1. Description and scope

This High-Level Use Case addresses the evaluation and implementation of innovative demand response (DR) programs and flexibility contracts for EV users and aggregators. The purpose is to ensure optimal integration of EVs into the electricity grid by aligning EV charging behaviour with DSO and TSO stability requirements. Testing spans urban, rural, maritime, and inter-urban contexts. Accordingly, the objectives are as follows:

1. **Review and analyse existing DSO and TSO grid flexibility services:** building on references from the project proposal, HLUC5 (workplace charging scenarios), HLUC8 (port charging scenarios), and HLUC11 (DSO-led flexibility services), compile a comprehensive set of EV-based flexibility services and assess technical, regulatory, and economic drivers.
2. **Simulate and assess EV grid service provision scenarios for technical and economic feasibility:** evaluate DR strategies that align charging with voltage/frequency needs and reduce peak load, using real-time data and AI-based forecasting (continuity with WP3–WP4).
3. **Development and validation of decision-making algorithms:** develop, implement, and test decision-making algorithms to optimize EV flexibility offerings across different operational scenarios and demonstration sites.
4. **Assessment of user acceptance and comfort:** conduct surveys and analyse user responses, participation willingness, and comfort levels related to DR programs and flexibility contracts across the different demonstration contexts.

4.1.2. Primary and specialized UCs

The HLUC consists of three Primary Use Cases:

- **PUC1.1 – Viable Flexibility Grid Services from EVs:** review of existing grid services and applicability in the European context. Understanding the best practices and feasibility with the country grid conditions. Exploiting the expertise and experience of the consortium members from DSOs, TSOs and research environment. Finally, filtering the research on e-mobility domain.
- **PUC1.2 – DSO-TSO Coordination and Flexibility Capacity Markets:** understanding how to implement flexibility services that do not harm the DSO or TSO. For example,

a solution to be tested is the implementation of conditional capacity agreements with the DSO and providing frequency services with the TSO.

- **PUC1.3 – Economic Feasibility and User Comfort:** simulation and forecasting with AI tools of smart charging programs for end users following the spot market, time of use tariffs and the possibility of entering balancing markets. Also, understanding if such smart charging algorithms compromise the user comfort and their participation.

The Specialized Use Cases defined by the demo sites are:

- **SUC1.1 – Nordic Europe Demo (Slow/fast charging demo):** addresses flexibility from workplace charging and fast highway charging infrastructure, considering renewable energy integration and battery storage.
- **SUC1.2 – Southern Europe Demo (Milan/Kranj):** focuses on flexibility services associated with electric bus depot charging operations.
- **SUC1.3 – Western Europe Demo (Lisbon and Funchal):** evaluates DR and flexibility services involving vessel charging and wireless EV charging systems.

4.1.3. Technical, economic, and regulatory feasibility

The feasibility of HLUC1 rests on developing and testing advanced DR strategies and flexibility contracts for EV charging across urban, rural, maritime, and inter-urban scenarios, using real-time data and AI-based forecasting to simulate and evaluate how EVs can provide grid services, such as peak load reduction, voltage support, and frequency regulation, while maintaining user comfort and coordinating interoperability, control algorithms, and interactions among EV users, aggregators, DSOs, and TSOs across multiple charging setups. Technically, EV-based DR and flexibility contracts are feasible using today's interoperable stack: smart-charging back ends (OCPP 1.6/2.0.1) and CPO–aggregator/DSO interfaces (IEC 63110, OCPI 3.0), with ISO 15118-20 enabling managed/bidirectional control where supported. Aggregator toolchains can combine AI forecasting with optimization to co-ordinate workplace, depot, highway and maritime loads, and to expose standard products (peak shaving, load shifting, voltage/frequency support).

In parallel, the use case evaluates the economic potential of DR programs and flexibility contracts by aligning charging behaviour with grid needs and testing participation in flexibility markets to explore cost savings, dynamic pricing incentives, and revenue opportunities, while examining business models and market mechanisms for DSO–TSO coordination that maximize value and minimize infrastructure investments through software-driven optimization.

The regulatory feasibility is supported by EU policies promoting smart charging, demand-side flexibility, and active consumer participation, particularly under EU Directive 2019/944 and Regulation 2024/1711, assessing how evolving market rules, aggregator frameworks, and contractual mechanisms enable new forms of flexibility trading, while addressing key challenges such as standardized communication protocols, system interoperability, data security, and user privacy; insights from this use case aim to guide regulatory frameworks.

4.2. HLUC2 – Charging Station with low-rated capacity

4.2.1. Description and scope

This High-Level Use Case focuses on optimizing EV charging stations with low rated capacity by integrating renewable energy sources (RES) and BESS. This is applied in both DC and AC charging stations and aims to create a control algorithm to managing the power distribution. Accordingly, the objectives are as follows:

1. Develop a smart management algorithm to optimize power usage.
2. Testing the integration of BESS and RES to optimize EV charging efficiency.
3. Optimizing power quality.

Imagine a typical day at a busy EV charging station located in an urban area. The station supports multiple EVs at the same time but is connected to the power grid with limited capacity. This limitation makes it impossible to fast-charge all connected vehicles simultaneously using only grid power. To tackle this, the charging station uses a smart management system that makes real-time decisions about how and when to deliver power to vehicles. The system includes a local energy storage battery and multiple charging outlets. It also has software that uses optimization algorithms to control how power is distributed across the station. From a user's point of view, the process is seamless. A driver arrives, plugs in their EV, and expects it to be charged within a reasonable amount of time. They may not realize that behind the scenes, the station is dynamically deciding how to balance power between several vehicles, possibly using stored battery energy when grid power is insufficient. For example, if three vehicles arrive around the same time, the system checks current grid availability, the energy stored in the battery, and the expected departure times of each vehicle. Based on this, it may decide to fast-charge one vehicle first using the battery, then gradually charge the others when grid demand is lower. This ensures that each vehicle receives the energy it needs without overloading the grid or causing unnecessary delays. In addition, the charging strategy can incorporate demand-response signals or flexibility requests from the DSO to shift charging demand away from peak periods and support grid stability. The expectation is that users

receive reliable, efficient charging without having to worry about the technical challenges of energy management. At the same time, the operator of the station benefits from lower energy costs (e.g., by avoiding peak-hour grid usage), better use of local battery storage, and the ability to serve more vehicles without needing an expensive grid upgrade. This use case demonstrates how smart energy management not only supports the growth of EV infrastructure but also improves user experience and system sustainability. It reflects a shift from simple plug-and-charge models to intelligent systems that coordinate multiple resources under real-world constraints.

4.2.2. Primary and specialized UCs

The HLUC consists of three Primary Use Cases:

- **PUC2.1 – Charging Optimization:** create an algorithm that dynamically allocates power between grid, BESS, and RES, optimizing charging speed, cost, and grid stability.
- **PUC2.2 – RES-BESS Coordination:** focused on balancing real-time RES generation and BESS charge/discharge to minimize grid dependence.
- **PUC2.3 – Scheduling vs Modulation Control Algorithm for Managing EV Charging Station:** compares pre-planned with real-time modulation. Assesses their impact on charging efficiency, grid stability, and user experience to determine the most effective strategy.

The Specialized Use Cases defined by the demo sites are:

- **SUC2.1 – Nordic Europe Demo (Slow/fast charging demo):** both locations will implement smart management of the available power, requesting only 22% (Location 1) and 32% (Location 2) of the total available capacity.
- **SUC2.2 – Southern Europe Demo (Milan/Kranj):** this demo explores the flexibility potential of both private and public EV fleets integrated into the grid. In Slovenia (Kranj), planning tools will be tested, and flexibility services will be simulated based on a charging park that is not yet operational. In Italy (Milan), real-world data from a charging hub with 96 V1G points serving a utility fleet operated by A2A will be used to simulate control strategies for power management and to evaluate the impact of temporal charging patterns.
- **SUC2.3 – Western Europe Demo (Lisbon):** Pilots 1 and 3 will utilize smart management of available power. Both cases will consider charging in parking lots and

management of multiple sockets. The main distinction is the scale and duration of parking. Location 1 is a residential garage with capacity for four EVSEs, but only two are currently available. Charging here is mostly during weekends or nighttime during the week. In contrast, location 2 is a semi-public parking lot that is mostly used by professionals during the day. I.e., parking is mostly during weekdays and during working hours.

4.2.3. Technical, economic, and regulatory feasibility

Technically, optimising low-rated AC/DC charging stations is feasible by deploying a site EMS with a smart scheduling algorithm to coordinate grid imports, a BESS, and RESs across multi-outlet EVSE. The key innovation is intelligent power sharing and multi-outlet energy distribution that keeps multiple charging points within grid constraints, supported by real-time monitoring of grid availability, RES output, and storage SOC, and by interoperability via common protocols, OCPP, IEC 61851, and ISO 15118, for seamless integration with existing infrastructure and back-end systems. The control stack can operate in both “scheduling” (ahead-of-time planning based on forecasted charging demand, expected charging profiles, and RES availability) and “modulation” (real-time set-point adjustment) modes to respect feeder and transformer limits, share power among sockets, and exploit PV/BESS for peak shaving and self-consumption.

Economically, smart power management and hybrid RES–BESS operation reduce the need for costly grid upgrades and enable cost-effective EV charging deployment, especially where grid capability is limited, by optimizing energy costs, shaving peaks, and shifting loads, while creating potential revenue via flexibility services for stakeholders such as CPOs, DSOs, and municipalities, and supporting a scalable model consistent with decentralized, flexible, energy-efficient mobility.

From a regulatory standpoint, the use case aligns with EU frameworks, particularly the Alternative Fuels Infrastructure Regulation (AFIR), and complies with relevant standards (IEC 61851 for controlled charging, ISO 15118 for vehicle-to-grid and Plug&Charge, OCPP 2.0.1 for back-end interoperability), accommodating national implementations and contributing insights to ongoing work on flexibility markets, conditional grid connections, and behind-the-meter services to inform future EU regulation and standardization.

4.3. HLUC3 – Cyber-secure charging platform

4.3.1. Description and scope

This High-Level Use Case focuses on the identification and evaluation of cybersecurity threats and vulnerabilities that affect EV charging infrastructures. It considers both existing deployments using open charge point protocol 1.6 and newer implementations adopting OCPP 2.x Plug&Charge. The analysis also evaluates the effectiveness of cybersecurity mitigations when applied to realistic threat scenarios. Accordingly, the objectives are as follows:

1. **Cybersecurity Analysis:** conduct an evaluation of existing threats and vulnerabilities affecting standard charging infrastructure, specifically communication protocols and charging station endpoints.
2. **Mitigation Capabilities:** analyse the effectiveness of selected mitigation strategies in preventing, detecting, or limiting the impact of cyberattacks.
3. **OCPP 2.x Plug&Charge:** assess the potential benefits and drawbacks of adopting OCPP 2.x Plug&Charge protocols, including an analysis of added security features, new threat vectors, and implementation challenges.

Cyberattacks targeting EV charging infrastructure can target user privacy, disrupt services, and pose safety risks. This use case addresses these challenges by simulating realistic threat scenarios and assessing their consequences on the charging ecosystem. The analysis centres on two major components of the charging infrastructure: the OCPP protocol and the charging station hardware. By executing controlled, domain-specific attacks, the study reveals vulnerabilities and impact pathways that are distinctive to EV charging environments. Building on these findings, it examines the extent to which newer protocol releases, such as OCPP 2.x, and endpoint-level protections can strengthen overall resilience. The resulting comparative analysis traces how successive OCPP versions improve communication security, harden authentication, and enhance protocol robustness under adversarial conditions. Charging station endpoints are also scrutinized to reveal potential weaknesses, with and without mitigation strategies in place. These evaluations enable the formulation of actionable recommendations for securing current and future deployments.

4.3.2. Primary and specialized UCs

The HLUC consists of three Primary Use Cases:

- **PUC3.1 – Threat Identification and Analysis:** this use case focuses on the identification of vulnerabilities and threats affecting EV charging infrastructure. It considers both legacy OCPP 1.6 deployments and newer OCPP 2.x implementations, including Plug&Charge functionalities. Threat modelling is performed by simulating cyberattacks against network communications and charging station endpoints. The objective is to classify the vulnerabilities, understand the impact on system confidentiality, integrity, and availability, and provide a baseline threat catalogue for the charging ecosystem.
- **PUC3.2 – Evaluation of Cybersecurity Mitigations:** this use case investigates the effectiveness of different cybersecurity countermeasures, including authentication, encryption, intrusion detection, and endpoint hardening. It compares their performance in preventing, detecting, or limiting the impact of simulated attacks on OCPP-based communication and charging stations. The analysis covers how these mitigations operate under different threat scenarios and provides insights into their applicability for real-world deployments.
- **PUC3.3 – Comparative Assessment of OCPP 1.6 vs OCPP 2.x Plug&Charge:** this use case provides a structured comparison between OCPP 1.6 and OCPP 2.x Plug&Charge protocols from a cybersecurity perspective. It examines how the adoption of OCPP 2.x improves security features such as authentication, encryption, and trust establishment, while also considering new vulnerabilities introduced by the added complexity of Plug&Charge. The goal is to highlight both the advantages and limitations of migrating to newer standards and to inform stakeholders about the security trade-offs of implementation choices.

The Specialized Use Cases defined by the demo sites are:

- **SUC3.1 – Nordic Europe Demo.**
- **SUC3.2 – Southern Europe Demo.**
- **SUC3.3 – Western Europe Demo.**

4.3.3. Technical, economic, and regulatory feasibility

The feasibility of HLUC3 centres on implementing and configuring a testbed capable of the planned security assessments, specifically, at least one charging station with support for OCPP 1.6 and 2.x and Plug&Charge, prerequisites already foreseen for the three demonstration work packages (WP7–WP9). Additional technical feasibility hinges on specialized competencies for threat simulation and mitigation analysis, which are covered by

the consortium's academic and industrial expertise. In practice, adoption can proceed incrementally by enabling OCPP 2.x and Plug&Charge alongside OCPP 1.6, allowing charging stations and EMS to operate in parallel during transition. The outcomes of HLUC3 will provide concrete configuration guidelines and mitigation patterns that reduce integration risk and support future scale-up on operational sites.

Economically, leveraging existing charging infrastructure and demonstration facilities at the pilot sites reduces the additional deployment, integration, and operational effort required for cybersecurity testing activities, although deployment of OCPP 2.x remains pending and may require extra integration and configuration effort. Moreover, cybersecurity testing must be carefully planned to avoid unintended side effects on the testbed, especially where environments are shared with production, which can raise complexity and costs for isolation, monitoring, and recovery mechanisms. In operation, a cyber-secure charging platform protects revenue (accurate billing, lower fraud/chargebacks), cuts O&M costs through faster incident detection/response and less downtime and extends asset life. For operators and DSOs/TSOs, higher trust in telemetry and control signals safeguards flexibility and settlement revenues, while greater user trust accelerates adoption and utilization rates.

From a regulatory perspective, all analyses and tests will be conducted in isolated and controlled environments, keeping the use case outside the scope of regulations applicable to operational infrastructure or consumer-facing services. In addition, any personal data used in experiments or simulations will be anonymized to ensure compliance with the General Data Protection Regulation (GDPR). Finally, the approach aligns with recent and upcoming European regulations, notably the Cyber Resilience Act and NIS2 directive, which emphasize cybersecurity testing and vulnerability assessment for connected and critical infrastructure. This use case directly supporting those objectives through systematic analysis, testing, and mitigation, thereby contributing to European goals for digital resilience and secure mobility.

4.4. HLUC4 – Novel charging technologies

4.4.1. Description and scope

This High-Level Use Case focuses on the demonstration of novel charging technologies, which will be achieved in a mix of real-world and simulated environment considering urban, rural, and maritime sector. Ultimately, this use case intends to form the technological basis for the development of some of the remaining AHEAD use cases. Accordingly, the objectives are as follows:

1. Deploy a matrix-based charging infrastructure to conduct exploratory tests on wireless charging in a private parking lot; participate in the retrofitting on an EV to support matrix-based charging; design and evaluate a use case that considers the possibility of using matrix-based charging in the daily operations at the parking lot.
2. Identify the charging infrastructure requirements for fleets of electric or hybrid vessels; retrofit an existing AC charging infrastructure to support monitoring and smart charging of small vessels; test and evaluate the performance of the developed system with vessels operating in real-world conditions.
3. Install a Kempower V2G charging station for the Southern Europe demo at Location 1 (Italy) to conduct real-world tests on the flexibility services that electric buses can provide to the DSO grid. At Location 2 (Slovenia), simulate charging strategies and the flexibility potential of HDVs and public transport fleets in a simulation environment.

This use case is dedicated to the analysis of innovative charging technologies across various contexts, including private parking lots, maritime environments, rural and urban areas.

In private parking lots, validation of novel charging technologies will be carried out through the deployment of a complete charging infrastructure, enabling an in-depth evaluation of wireless charging functionality. This includes the retrofitting of an EV to ensure compatibility with the wireless charging system. The technology will be assessed within a matrix-based smart charging framework designed to optimise day-to-day operations in the parking lot. The framework comprises the installation and monitoring of EV energy consumption, the measurement and control of charging station performance, the implementation of automated control actions for charging processes, the development of a management dashboard for parking operators, and a graphical interface for EV owners. The anticipated results include optimised daily operations through reduced downtime and fewer manual interventions, as well as increased interest in wireless charging technologies among parking lot operators and EV users.

Heavy-duty and bus charging will be analysed using both real-world demonstrations and simulations. In Italy, a Kempower V2G charging station will be used to test electric bus fleets and their potential to provide flexibility and support to the DSO grid. In Slovenia, simulation studies will investigate the flexibility contribution of HDVs and public transport fleets. The outcomes will provide insights into scalability, optimal fleet charging strategies, and the range of grid services that such fleets can offer.

The maritime-oriented activity focuses on identifying the main charging infrastructure requirements for fleets of electric or hybrid vessels. An AC shore charging infrastructure supporting monitoring and control of small vessels will be implemented to validate smart charging operations in a real-world port scenario. As in the parking context, a smart charging framework will be used to coordinate multiple charging points, including real-time monitoring of vessel energy consumption, performance assessment and control of charging stations, and advanced control actions to enhance operational efficiency. In addition, a comprehensive management dashboard will be developed for both the DSO and the port authority, complemented by a graphical interface designed to support the needs of vessel operators. Expected outcomes include validating the framework's capability to provide accurate and continuous monitoring, enabling effective control strategies for seamless operation and load balancing, optimising the management of charging resources to meet vessel energy demands while preserving system stability, and strengthening data-driven decision-making processes for the DSO and port authority through a centralised management environment.

4.4.2. Primary and specialized UCs

The HLUC consists of three Primary Use Cases:

- **PUC4.1 – Matrix-based Charging Technologies:** understanding the installation requirements for matrix-based charging, performing the installation and retrofitting an EV to enable testing the charging technology. It is important to stress that the charging will be bi-directional in AC. A key characteristic of the use case is the simulation of dynamic charging and parking patterns, including repeated arrivals and departures of the same EV during the day, in order to evaluate matrix-based charging technologies under realistic operating conditions and different charging-management strategies, including uncoordinated charging and V1G operation.
- **PUC4.2 – Vessel Charging Technologies:** understanding how electric and hybrid vessels dedicated to maritime-touristic activities (e.g., catamarans) can be charged. This case will focus on AC charging, and for that effect the team will retrofit an existing electricity supply point to also support the smart charging of such vessels. A key characteristic of this retrofitting is that it will support the sending of ON and OFF commands to the charger using OCPP.
- **PUC4.3 – Heavy-Duty/Buses Charging:** understanding how electric buses and heavy-duty vehicles can contribute to flexibility services through smart and bidirectional charging. In Location 1 (Italy), a Kempower V2G charging station will be installed and connected to an electric bus to test real-world capabilities of energy

withdrawal reduction and energy injection into the DSO grid. In Location 2 (Slovenia), simulations will be conducted to evaluate charging strategies and flexibility potentials for HDVs and public transport fleets.

The Specialized Use Cases defined by the demo sites are:

- **SUC4.1 – Western Europe demo – Lisbon:** the charging system (matrix-based charger) will be installed in the EDP parking lot in Lisbon and integrated into the existing platform of controlling EVSEs. Ideally the charger will also be integrated into the birdsEView platform. In the end, it should be able to test bi-directional charging.
- **SUC4.2 – Western Europe demo – Funchal:** the vessel charging system will be integrated in the birdsEView platform, developed for the Western European demos, and will include a mobile application to visualize and change the status of the chargers. In the end, it should be possible to test the developed system using at least one of the vessels in the Port of Funchal.
- **SUC4.3 – Southern Europe demo:** for Location 1 (Italy), the bus charging system will be installed at the A2A test site, located in the parking lot/charging hub within the primary substation (HV/MV) in Milan. The system will include a Kempower charger with 80 kW continuous power and up to 100 kW peak power. An advanced interface will be exploited to control the bidirectional charging process, enabling coordination between the charger, the bus battery, and the electrical grid. For Location 2 (Slovenia), the charging park will be simulated based on the simulation tool that will be developed in WP3. The idea is to analyse what kind of flexibility capacity the HDV/transport fleets/cars charging park will have and would offer to the DSO network via flexibility services. In real time and based on the active power consumption at the primary transformer station, the flexibility of EV charging will be simulated to emulate the provision of flexibility services at the demo location.

4.4.3. Technical, economic, and regulatory feasibility

Across the three locations, the technical feasibility of HLUC4 builds on existing assets and targeted upgrades. Technically, the three strands, matrix-based (wireless) EV charging, AC vessel charging, and HDV/bus charging including V2G, are feasible. In Lisbon (EDP parking lot), a dedicated area will host a matrix-based charger connected to the secondary substation. One EDP vehicle will be retrofitted to enable the new charging method. In Funchal Port, where no dedicated electric-boat chargers exist, a general-purpose SPD will be retrofitted to support vessel smart charging and remote monitoring/control; given the small number of small electric/hybrid boats, power needs remain modest and fit the current capacity. In Milan (A2A

test site), the V2G charger will be installed near the secondary substation within an already suitable electrical setup, with space for the battery used to simulate the electric buses. In Slovenia, the scenario relies on the WP3 simulation tool and Elektro Gorenjska's existing network simulators, so no major technical barriers are expected. In perspective, these steps provide a practical path to future real-world deployment: retrofitting, OCPP integration, and secondary-substation connections are all repeatable activities that can be scaled as demand grows.

Economically, the matrix-based charger in Lisbon enables unattended smart charging and better parking-lot load management, creating conditions for participation in grid services and improving vehicle availability while parked. In Funchal, retrofitting the SPD lowers upfront costs for a single-charger pilot, with smart charging (load management, energy optimisation) potentially reducing operational costs under variable electricity prices and peak-demand charges. In Milan, bi-directional charging can access grid services, and high-rate chargers increase revenue potential even with occasional activations. In Slovenia, an already built flexibility platform will monitor the simulated network and steer charging-park flexibility to optimise network parameters. In perspective, these pilots clarify cost drivers and revenue options and can shorten time-to-scale by reusing designs, procurement, and operating procedures proven in the demonstrations.

From a regulatory standpoint, the use case in Lisbon aligns with existing wireless EV charging standards and frameworks rather than any single regulation on “matrix-based charging”, referencing the IEC 61980 series and ISO 19363 for wireless power transfer; vessel charging follows national energy regulations, port-authority requirements, and international guidelines such as IEC 60309 for socket-outlets. Adoption of OCPP 1.6/2.0.1 supports regulatory compliance by enabling public access and interoperability, as required by the EU's AFIR. In all remaining cases, the solution will adhere to IEC 61851 for controlled charging, ISO 15118 for vehicle-to-grid communication and Plug&Charge functionality, and OCPP 2.0.1.

On the digital side, every platform integration will be carried out in line with GDPR, ensuring secure management of all data.

4.5. HLUC5 – Smart charging in workplaces

4.5.1. Description and scope

This High-Level Use Case aims to evaluate innovative smart charging solutions for EVSE at workplaces. Primarily emphasizing aspects as flexibility services, renewable energy integration and inclusion of dynamic pricing models based on DSO information in both

countries, Portugal and Denmark. A key aspect of these use cases will be the testing and comparison of distributed and centralized versions of the services where distributed version can be applied. Accordingly, the objectives are as follows:

1. Develop and test, in the real-world testbed, distributed (and centralized) scheduling algorithms that maximizes the self-consumption from RESs, while ensuring that the EV charging objectives are met.
2. Develop and test, in the real-world testbed, distributed (and centralized) scheduling algorithms that reduce the number of times that voltage and frequency PU values are outside the permitted ranges, e.g., $0.95 < V_{pu} < 1.05$ (MV) $0.90 < V_{pu} < 1.1$ (low voltage (LV)).
3. Develop and test, in the real-world testbed, distributed (and centralized) scheduling algorithms that is able to balance self-consumption and voltage/frequency. Additionally, the objective includes identifying key trade-offs between the two competing objectives.

This use case, in Portugal, aims to develop and validate scheduling algorithms in both distributed and centralized that enhance self-consumption from RESs and minimize charging costs by leveraging periods of lower electricity prices. The smart charging algorithms will optimize charging schedules to align EV energy demand with available renewable generation, reducing dependency on grid electricity and enhancing sustainability. The overall framework includes the deployment and continuous monitoring of EV energy consumption, the assessment and regulation of charging station performance, and the implementation of control mechanisms for charging stations. Furthermore, the aggregation platform will deliver forecasting analytics and charging optimization data to a dashboard for parking lot operators, while also providing an intuitive graphical interface for EV owners.

In Denmark, testing will take place in a rural setting, leveraging existing infrastructure to evaluate distributed versus centralized flexibility services for network operators. The study will focus on balancing grid stability (voltage and frequency control) with maximizing self-consumption of RESs. Additionally, dynamic pricing mechanisms based on DSO data will be implemented in collaboration with industry partners to assess their impact on charging behaviour and infrastructure utilization.

Ultimately, the anticipated outcomes of this UC include self-consumption maximization by optimizing charging schedules to align EV energy demand with available renewable generation, thereby reducing reliance on grid electricity and enhancing sustainability.

Additionally, cost optimization will be achieved through dynamic charging schedules based on real-time electricity prices, shifting consumption to lower-cost periods while maintaining user requirements.

4.5.2. Primary and specialized UCs

The HLUC consists of four Primary Use Cases, “C” stands for centralized, whereas “D” stands for distributed:

- **PUC5.1C | PUC5.1D – Maximization of Self-Consumption from RESs:** this use-case focuses on maximizing self-consumption from RESs by developing and testing distributed and centralized scheduling algorithms in a real-world testbed. This will be achieved by using predictive control and control algorithms that adjust EV charging considering the presence of RESs while ensuring the EV charging objectives are met.
- **PUC5.2C | PUC5.2D – Voltage and Frequency Control:** the voltage and frequency fluctuations will be addressed by implementing real-time adjustments to EV charging loads based on grid conditions. The system will integrate voltage and frequency monitoring with predictive control algorithms, helping stabilize voltage and frequency variations, ensuring grid reliability.
- **PUC5.3C | PUC5.3D – Dynamic Pricing from DSO signals:** PUC5.3 aims to reduce EV charging costs through dynamic pricing by incorporating signals from the DSO into charging schedules. By collecting pricing signals from the DSO, cost-optimization algorithms will be developed, implementing adaptive charging schedules. By aligning charging activities with lower price periods, both the users and the grid will benefit.
- **PUC5.4C | PUC5.4D – Multi-objective: PUC5.1 + PUC5.2:** a multi-objective optimization model is explored. This model considers both maximisation self-consumption (PUC5.1) and voltage and frequency control (PUC5.2). With its implementation in a real-world testbed, it will be identified the key trade-offs between these two conflicting objectives.

The Specialized Use Cases defined by the demo sites are:

- **SUC5.1a – Western Europe demo – Lisbon:** at EDP parking lot in Lisbon, there are currently 64 EV chargers, with plans to extend that number up to 67. These chargers operate alongside other energy consumers, including office buildings and an electric bus. Since the PV generation at the site supplies power to all these loads, there are times when it is insufficient to support all charging needs, limiting the availability of the

chargers. In this context, a smart scheduling solution will be studied for a real-world application in order to maximize self-consuming from RESs while ensuring EV charging objectives are met, which will reduce the stress on the grid during peak hours and enable a more efficient use of the PV. Additionally, by optimizing charging strategies around the introduction of RESs, it could expand PV capacity.

- **SUC5.1b – Nordic Europe demo – Slow charging demo:** the parking lot at DTU Risø has multiple EVSEs of different brands. The chargers operate alongside the office buildings and are connected to SYSLAB, including RESs. The chargers can be controlled in a way to maximise self-consumption.
- **SUC5.2a – Nordic Europe demo – Slow charging demo:** the parking lot at DTU Risø has multiple EVSEs of different brands. The chargers operate alongside the office buildings and are connected to SYSLAB, including RESs. The chargers will be used to test voltage and frequency support strategies through dynamic control of EV charging loads.
- **SUC5.3a – Western Europe demo – Lisbon:** currently, only four of chargers in the parking lot (this number will increase to seven in the future) are fully controllable, allowing for direct adjustments to the charging schedules. The remaining 60 chargers are managed by a third-party application. To reduce the charging costs and promote implicit demand response on the parking lot, a smart charging solution will be studied considering its usual charging patterns alongside dynamic pricing signals from the DSO. By collecting electricity price signals, the system will develop and implement adaptive charging schedules that align EV charging with periods of lower electricity costs.
- **SUC5.3b – Nordic Europe demo – Slow charging demo:** the parking lot at DTU Risø has multiple EVSEs of different brands. The chargers operate alongside the office buildings and are connected to SYSLAB, including RESs. The chargers can be controlled in a way to respond to dynamic price signals.
- **SUC5.4 – Nordic Europe demo – DTU-Risø campus:** the parking lot at DTU Risø has multiple EVSEs of different brands. The chargers operate alongside the office buildings and are connected to SYSLAB, including RESs. The chargers can be controlled in a way to contribute to multiple objectives at once.

4.5.3. Technical, economic, and regulatory feasibility

Smart workplace charging is readily deployable with today's stacks. Centralized or distributed EMS can orchestrate AC EVSE using mature interfaces (e.g., OCPP 1.6/2.0.1 for control and metering) and standard charger/grid telemetry. Forecast-based scheduling (PV, load, price), constraint handling (site/feeder limits), and multi-objective optimization (self-consumption vs. voltage/frequency bounds) are well understood. HLUC5 builds on existing workplace EV infrastructure in Portugal and Denmark while focusing on integrating smart algorithms with heterogeneous chargers. In Lisbon, the parking lot already operates 64 chargers (with plans to expand to 67), mixing fully controllable units with third-party devices limited to simple ON/OFF control; the core challenge is achieving seamless coordination across these differing control architectures. In Denmark, the upgraded SYSLAB infrastructure will integrate existing and new EV-charging assets from different brands. Looking ahead, once integration patterns for mixed fleets (fully controllable + third-party) are validated, they can be replicated across sites via the EMS. The main risks relate to charger/vendor-specific behaviours, data quality from EVSEs, and ensuring near real-time voltage/frequency inputs for reliable control.

Economically, the use case targets cost savings by optimising charging against local PV or other on-site generation (PUC5.1) and low-price periods (PUC5.3), while voltage and frequency control (PUC5.2) enables participation in remunerated grid services. Retrofitting and software development costs remain moderate, as most effort is concentrated on integration and control-algorithm development. In perspective, validated scheduling reduces energy spend, avoids peak charges, and increases utilisation of the few fully controllable chargers; main sensitivities are the share of PV available, the fraction of controllable vs third-party chargers, and the stability of DSO price signals.

Regulatory feasibility is supported by the European framework promoting electrification, decarbonisation, and flexible demand. In particular, the Electricity Directive (EU) 2019/944 encourages active consumer participation and demand response, providing a legal basis for smart charging guided by dynamic pricing signals (PUC5.3). A practical challenge remains the lack of standardisation across chargers from different manufacturers, which complicates integration, especially when coordinating fully controllable units with limited third-party devices, as seen at the EDP workplace. In perspective, converging on common control interfaces and protocol profiles will ease replication and reduce integration risk across additional workplaces. Potential issues are differing national implementations and the need to handle consent and data handling consistently when exchanging signals with the DSO and third-party systems.

4.6. HLUC6 – Smart charging at depots

4.6.1. Description and scope

This High-Level Use Case focuses on optimizing the charging of HDV and public transport electric buses, thereby improving grid utilization in urban areas through smart depot charging methods. Accordingly, the objectives are as follows:

1. Assess business as usual charging without smart algorithms: monitor the energy consumption of battery electric buses (BEBs) to identify patterns and inefficiencies, observe the utilisation rates of charging stations to understand peak usage periods and potential bottlenecks, and analyse the uncoordinated charging process to pinpoint where energy and time are being wasted.
2. Analyse and optimize electric bus charging: collect data from the DSO, public transport operators, and charging management systems; develop algorithms to optimise charging schedules based on SOC, grid demand, and departure times; and ensure that charging is performed in a cost-efficient and grid-friendly manner.
3. Analyse electric bus charging with V2G integration: implement V2G functionality to allow energy to flow both to and from the grid and use electric buses as grid assets to help stabilise the grid during demand fluctuations.
4. Analyse a smart charging hub for HDVs, buses, and cars: include the entire fleet of electric vehicles (HDV/ bus/car) in the simulation, use historical data from the SCADA system to define scenarios and run simulations, and develop a smart charging system capable of recalculating power and charging duration for all EVs based on real-time data and requests.

The Smart Charging at Depots Use Case will explore how to implement smart charging for electric vehicles, particularly heavy-duty vehicles such as public transport buses and trucks. The aim is to understand how optimization algorithms can be applied to determine the optimal charging schedule for each vehicle.

Currently, depot charging typically occurs in an uncoordinated manner, where BEBs charge at maximum power as soon as they return to the depot, continuing until fully charged. This uncoordinated approach is inefficient. Efficiency can be significantly improved by introducing smart charging. Since battery electric buses usually remain in the depot for long periods, their charging process can be managed in a way that benefits the DSO, the CPO, and the public transport operator (PTO).

To achieve the objective of this use case, several actions need to be performed:

- **Scheduling and Optimization:** develop and implement a scheduling and optimization algorithm that assigns variable charging currents to different periods of the charging process. This minimizes costs while ensuring that distribution grid limits are not exceeded.
- **Design of V2G Charging Infrastructure:** install a new V2G-capable charging station, provided by Kempower, to evaluate the benefits of flexibility services. This includes both reducing energy withdrawal and enabling controlled energy injection into the DSO grid.
- **Quantification of Flexibility:** analyse and quantify the potential flexibility offered by vehicle batteries as distributed energy storage. Based on the results, the DSO may activate flexibility contracts to enhance grid stability and reliability.

This use case will involve a diverse range of applications and stakeholders, including electric vehicle operators, energy providers, charge point operators, and public transport operators. It will evaluate the technical, economic, and regulatory feasibility of smart depot charging, aiming to demonstrate the benefits of optimized bus fleet management and its implications for the medium-voltage grid.

4.6.2. Primary and specialized UCs

The HLUC consists of four Primary Use Cases:

- **PUC6.1 – Business as Usual Charging:** the first PUC covers the traditional, uncoordinated charging process, where buses charge on a first-come, first-served basis without considering grid constraints or optimization. The scope includes monitoring the energy consumption of BEBs, tracking charging station utilization, and identifying inefficiencies in the charging process.
- **PUC6.2 – Electric Bus Smart Charging:** the second PUC expands the scope to include smart charging techniques. It involves data acquisition from the DSO, PTOs, charging management systems, etc. The scope includes optimizing charging schedules based on factors such as state of charge, grid demand, and departure schedules. This ensures that charging is performed in a cost-effective and grid-friendly manner.
- **PUC6.3 – Electric Bus Smart Charging with V2G Integration:** The third PUC further extends the scope by incorporating bidirectional energy flows through V2G technology.

This scenario focuses on utilizing electric buses as grid assets, allowing energy to be withdrawn from or injected into the grid based on demand fluctuations. The scope includes grid stabilization, peak shaving, and increased renewable energy utilization, making BEB charging more sustainable and flexible.

- **PUC6.4 – Smart HDV/bus/car park charging:** the fourth PUC considers the total fleet of electric vehicles (HDV/bus/car), which will be simulated and activated based on consumption data from the primary transformer station obtained via the SCADA system. The objective is to design a smart charging system capable of dynamically recalculating charging power levels and durations for all EVs in the depot when required.

The Specialized Use Cases defined by the demo sites are:

- **SUC6.1 – Southern Europe demo - Milan:** in-field validation of smart (and V2G) depot charging for battery electric buses at A2A's site: integration with DSO and charging management systems, schedule optimization versus SOC and departures, and measurement of impacts on costs and MV grid usage.
- **SUC6.2 – Southern Europe demo - Kranj:** simulation of smart charging for a mixed fleet (HDV/bus/car) using primary substation SCADA time series: testing scheduling algorithms, dynamic recalculation of charging power/duration, and flexibility scenarios toward the distribution grid.

4.6.3. Technical, economic, and regulatory feasibility

Technically, smart depot charging for HDVs and electric buses is feasible in the near term using existing building blocks: an EMS that ingests SOC data, depot schedules, and DSO constraints; interoperable control and telemetry with EVSE via IEC 63110 and back-office roaming via OCPI 3.0; vehicle/EVSE managed charging, and, where available, V2G, per ISO 15118-20; and grid interfacing/visibility through SCADA and IEC 61850-90-8. Cybersecurity aligns with IEC 62351 and ISO/IEC 27019, and data handling follows GDPR principles (data minimization, purpose limitation, and consent/legitimate interest). Key technical risks, including heterogeneous fleets, transformer limits, communications latency, and baseline errors/model drift, should be considered.

Economically, the use case assesses how energy optimisation and bidirectional operation can reduce costs for the PTO and the DSO, quantify the value of flexibility, and inform DSO on scalability and the potential to defer grid investments; in practice, outcomes will hinge on duty

cycles, energy prices, charging windows, and the reliability of EMS data, with flexibility revenues weighed against capital and integration costs.

From a regulatory standpoint, the charging infrastructure will align with the AFIR, ensuring smart functionalities and interoperability. Technical design and communications will follow EU-recognised standards, IEC 61851 for smart charging operations, ISO 15118 for vehicle-to-grid communication and Plug&Charge, and OCPP for backend management and data interoperability. In perspective, conformity with these standards and demonstrated interoperability at the depot will support approvals and facilitate replication across similar sites operating under DSO interconnection rules.

4.7. HLUC7 – Smart charging in highways

4.7.1. Description and scope

This High-Level Use Case focuses on implementing smart charging along highways. Location 1 will test the coordination of a hybrid battery energy storage system and renewable energy sources (BESS + RESs) at a buffered fast-charging station. In this context, the sensitivity of utilisation rates to charging prices will be assessed. Additionally, the SYSLAB facilities will be used to demonstrate LV grid challenges, as well as flexibility-based solutions for the DSO (emulated by SYSLAB) and the TSO. Accordingly, the objectives are as follows:

1. Develop a multi-objective framework to optimize energy buffering.
2. Identify user needs and price sensitivity.
3. Highlighting main grid planning challenges and proposing cost-effective compensations.
4. Integrating flexibility services into the existing optimization platform.

The demonstration exercises an end-to-end highway fast-charging hub buffered by hybrid on-site resources, where a battery energy storage system and local renewable generation (PV) enable 150 kW fast charging despite a constrained grid connection of roughly 43 kW. The BESS and PV are coordinated to meet power demand, respect grid limits, and preserve service quality. A multi-objective EMS manages grid imports, BESS charge/discharge, and PV utilization to secure available power at the charger while minimizing curtailment, maximizing self-consumption and self-sufficiency, and exploiting time-shifting.

Fast-charging operations are paired with alternative pricing approaches to measure their effects on utilization, waiting time, and user satisfaction, allowing the project to quantify price elasticity without compromising quality of service. Using SYSLAB, the project observes and

emulates low-voltage network conditions e.g., congestion, transformer loading, voltage drop, and total harmonic distortion (THD) under realistic fast-charging profiles. We then tests cost-effective mitigations such as BESS set-point policies, PV smoothing, ramp-rate limits, and charger power-factor control. Whenever operating conditions allow, the EMS also exposes flexibility to the DSO/TSO, reducing imports or providing upward/downward reserve, via coordinated BESS–charger control.

4.7.2. Primary and specialized UCs

The HLUC consists of four Primary Use Cases:

- **PUC7.1 – Management of a Hybrid (BESS+RES) Buffered Fast Charging Station:** developing a multi-objective framework to optimize energy buffering. Outlining revenues, costs, and constraints for optimization. Highlighting the sensitivity and constraints of hardware. Identify recommendable periods for charging and discharging the battery system.
- **PUC7.2 – User Response to Dynamics Charging Price Approaches:** identifying KPIs for maximizing user experience. Determining the sensitivity of the user to the prices, either fixed or variable.
- **PUC7.3 – LV Grid Planning Challenges and Solutions:** determining possible challenges such as congestion, transformer overload, voltage drop or high THD levels. Identifying potential compensation methods and investigating whether they are worth the investment.
- **PUC7.4 – Test Flexibility Services for DSOs and TSOs:** finding mandatory flexibility services and adequate flexibility markets for the size of the application. Identifying optimal times and constraints to participate in the market. Testing feasibility of market participation.

The Specialized Use Cases defined by the demo sites are:

- **SUC7.1 – Nordic Europe demo – Fast charging demo:** Location 1 at Risø campus is located in the Danish countryside and gives the possibility for all users to utilize the newly installed fast-charging infrastructure provided by KEMPOWER (operated commercially by SPIRII). In addition, due to reduced grid capacity (43 kW availability) the location will utilize the combination of a BESS from Pixii (325kWh/150kW) and local PV production to deliver 150 kW of fast charging. This combination resembles future charging hubs and reduces the grid capacity requirements.

4.7.3. Technical, economic, and regulatory feasibility

The feasibility of HLUC7 builds on a battery-buffered fast-charging point (≈ 180 kWh/120 kW) operating behind the meter with co-located renewable energy sources, coordinated to deliver flexibility services while accounting for line losses on a ~ 600 m feeder. Battery-buffered fast charging is already well established in practice and literature. With the added storage and RES, charging power can be modulated and scheduled to meet application priorities and grid limits. Highway smart charging buffered by on-site resources is feasible. An EMS can schedule grid imports, BESS charge/discharge, and PV utilization to meet charging sessions, minimize curtailment, and mitigate LV issues. Key risks include charger–platform interoperability (CPO/EMS/BESS), data quality for PV/BESS/EV telemetry, and control tuning under variable utilization.

Economically, the reduced interaction with the grid and the siting of the hub support lower electricity costs and create multiple revenue streams, fast-charging sales supplemented by flexibility services, while the buffer helps contain capacity needs and associated charges. However, payback is highly sensitive to local traffic (utilization) and electricity prices.

From a regulatory standpoint, the behind-the-meter setup can be treated as a virtual power plant (see HLUC10). With conditional connection agreements (see HLUC1), the site can request capacity from the DSO and provide contracted flexibility within existing frameworks. Real-world sites will require DSO permissions for operating storage alongside fast chargers, clear limits on export/curtailment, and explicit processes for any DSO/TSO flexibility participation.

4.8. HLUC8 – Smart charging in port areas

4.8.1. Description and scope

The demonstration is part of the Western Europe demo site, specifically in the city of Funchal, Madeira. The HLUC is centred on the development of a hardware-in-the-loop (HIL) simulator to assess the impact of smart versus uncoordinated vessel charging on the power grid. The simulator uses real-world data and integrates charging infrastructure, digital twins, and smart meters to reproduce realistic port operating conditions. The system supports grid flexibility by enabling smart charging in response to requests from the DSO. Future extensions will incorporate battery storage, solar PV, and a planning tool for energy forecasting and optimisation. Given the relatively predictable operational patterns of maritime-touristic activities, including scheduled routes and docking periods, the planning tool will also exploit vessel timetables and charging availability windows to improve charging coordination and

energy management. The overall goal is to guide efficient, flexible vessel charging that supports both port operations and grid stability. Accordingly, the objectives are as follows:

1. In the context of PUC8.1, to develop a hardware-in-the-loop simulator (using the vessel charger developed in HLUC4) enabling the simulation of different levels of electrification of maritime-touristic activities, and to perform simulations to assess the impacts of uncoordinated vessel charging using KPIs such as minimum and maximum aggregated demand and the total time that peak demand is above or below a defined threshold.
2. In the context of PUC8.2, to extend the simulator to include stationary storage devices, simulate different smart-charging alternatives, and benchmark these solutions against the baseline results obtained in PUC8.1.
3. In the context of PUC8.3, to further extend the simulator to incorporate flexibility requests from the DSO, simulate smart-charging alternatives that can accommodate such requests, and benchmark the results against those obtained in PUC8.2.

Within this use case, the HIL simulator is the core tool for analysing the effects of uncoordinated and smart vessel charging, across different levels of electrification and flexibility. It uses the vessel charger developed in UC4 to create a realistic testing environment for maritime-touristic electrification. Simulations quantify the impact of uncoordinated charging using key performance indicators such as minimum and maximum aggregated demand and the total duration for which peak demand exceeds or remains below predefined thresholds. The simulator is then enhanced through the integration of flexibility requests from the DSO and the development of smart-charging alternatives that reconcile DSO flexibility needs with efficient vessel charging operations.

The investigation of this technology is structured around the birdsEView aggregator vessel smart charging framework. In an initial step, this framework integrates real-world data collection, digital twin simulations, renewable energy management, and demand response to optimise electric vessel charging at ports. Smart meters and EV chargers communicate via the OCPP, sending real-time measurements to the birdsEView aggregator. The port simulator generates trip-based simulations using historical data, modelling vessel and charger behaviour, while the initial set of port assets includes vessel models and charger performance analysis.

As the framework evolves, BESSs and solar PV are added to the port assets, enhancing renewable integration. A planning toolbox is introduced to support forecasting,

charging optimisation, cost reduction, increased self-consumption, and peak demand reduction, thereby improving energy efficiency and sustainability. Insights produced by the system, made available through the birdsEView dashboard and applications, enable port authorities and vessel companies to make informed, data-driven decisions.

Further enhancements include the introduction of a city-chargers module, connecting to public EVSEs to coordinate private and public charging. The planning toolbox is extended to cover grid services, optimising energy distribution. In parallel, the birdsEView flexibility sandbox enables demand response and interaction with DSOs. By combining real-time monitoring, predictive simulations, and advanced energy planning, the system supports port electrification, improves operational efficiency, and facilitates seamless grid integration.

The anticipated outcomes of this use case include a validated HIL simulator capable of assessing the impact of vessel electrification under multiple scenarios, providing stakeholders with clear insights into the effects of uncoordinated and smart vessel charging on the electrical grid. The system delivers a framework for integrating stationary storage solutions based on BESS, and a comprehensive evaluation of flexibility mechanisms and their role in demand-side management and efficient energy distribution. Finally, the planning toolbox and the birdsEView flexibility sandbox underpin recommendations for optimal smart-charging strategies that balance vessel charging needs with DSO flexibility requirements, contributing to resilient and sustainable port operations.

4.8.2. Primary and specialized UCs

The HLUC consists of three Primary Use Cases:

- **PUC8.1 – Uncoordinated Charging Impact Analysis:** through simulation it will be possible to establish a baseline scenario for different levels of vessel electrification (until 100%), without any smart charging in place.
- **PUC8.2 – Electric and Hybrid Vessel Smart Charging:** introduces smart charging solutions that consider only the needs of the port and business, optimizing energy use to reduce costs and ensure operational reliability (e.g., lowering the bill and making sure that the tourism operations are not compromised).
- **PUC8.3 – Grid-Aware Smart Charging with Flexibility from DSO:** builds on PUC8.2 by incorporating external signals from the DSO, enabling the port to provide dynamic grid support (e.g., responding to DSO requirements for flexibility).

The Specialized Use Cases defined by the demo sites are:

- **SUC8.1 – Uncoordinated Charging Impact Analysis – Western Europe Demo – Funchal:** use case is specific to the maritime-touristic activities taking place in the Port of Funchal. At present, only one hybrid vessel is in operation; therefore, it is necessary to develop a simulation platform capable of modelling both vessels and their trips. For this case study, different levels of electrification will be considered, up to a scenario in which 100% of the vessels in the marina are electric or hybrid. Simulations will be carried out assuming uncoordinated charging, i.e. when, upon docking, each vessel starts charging until the battery is full or another trip begins. The objective is to establish a baseline for energy costs and grid constraints that would arise if no smart charging strategies were implemented.
- **SUC8.2 – Electric and Hybrid Vessel Smart Charging – Western Europe Demo – Funchal:** this use case extends SUC8.1 by introducing smart charging algorithms as well as the presence of onsite RESs and BESS. The simulation will follow the same levels of electrification defined SUC8.1. The smart charging will focus on specific objectives, including costs reduction, peak demand management, and maximizing the levels of RES self-consumption. A direct comparison will be made against the results obtained for SUC8.1.
- **SUC8.3 – Grid-Aware Smart Charging with Flexibility from DSO – Western Europe Demo – Funchal:** this use case extends SUC8.2 by introducing flexibility requests from the DSO. During this use case, explicit (also known as incentive-based) demand response will be considered. Different levels of electrification will be simulated as well as different levels of response-rates from the demand-side (e.g., by defining different willingness levels to participate in the DR actions for each vessel).

4.8.3. Technical, economic, and regulatory feasibility

Smart charging in port areas is technically feasible with mainstream building blocks: marine-rated EVSE at berths; a site EMS to schedule charging across berths; communications via OCPP 1.6/2.0.1; and optional PV/BESS for peak shaving and resilience. Key requirements include sufficient grid headroom at the secondary substation and along quay feeders, interoperability with heterogeneous small craft (different DC limits, SOC telemetry availability), and robust operational control (dynamic per-berth setpoints, queueing, and priorities tied to departure times). Specifically, in HLUC8 a HIL simulator to study vessel-charging scenarios in Funchal's port will be developed. The hardware component will be the retrofitted charger from HLUC4, integrated into the port's existing infrastructure to provide a real-world testbed. The main challenge lies in its scalable simulation design, where each phase, represented by

the PUCs, builds progressively on the previous one, starting with a simple charging scenario and systematically adding layers for smart charging.

From an economic perspective, HLUC8 feasibility depends on whether investment and maintenance costs are offset by savings in operating maritime-touristic activities using hybrid or fully electric vessels. These scenarios must be considered for both the port manager and the maritime-touristic operators. The HIL simulator reduces upfront risk by enabling scenario testing before physical deployment and, while initial investments are needed for BESS and RES integration along with algorithm development, long-term benefits include reduced peak-demand charges and cost savings due to smart scheduling.

The implementation of smart vessel charging in the Port of Funchal aligns with key European Union regulations, such as the AFIR, which aims to ensure sufficient electricity supply infrastructure for docked vessels in European ports, and the FuelEU Maritime Regulation, which encourages the use of electricity and other alternative fuels to reduce greenhouse-gas emissions. Both initiatives fall under the Fit-for-55 package, supporting EU climate objectives by promoting the decarbonization of transport sectors, including maritime operations. For conducting the simulations, some data may need to be collected from maritime-touristic operators (e.g., operation schedules and vessel information). In all cases, GDPR guidelines for data collection and sharing will be followed, ensuring robust handling of potentially sensitive information.

4.9. HLUC9 – Coordinated charging via charge point operators

4.9.1. Description and scope

This High-Level Use Case focuses on testing user engagement in AI-driven charging strategies and demonstrating the coordination of CPOs. It aims to evaluate how users interact with charging strategies informed by artificial intelligence and to explore how various charging vendors can work together to offer flexible services. Additionally, the use case will assess the benefits of these flexibility services for DSOs and TSOs. This use case aims to improve the coordination between EV charging networks and grid operators, ensuring a more efficient and flexible energy system. Accordingly, the objectives are as follows:

1. Evaluating user-engagement in AI-informed charging strategies.
2. Testing coordinated charging by CPOs.
3. Testing flexibility services for DSOs and TSOs.

The Coordinated Charging via CPOs use case explores how EV users engage with AI-driven charging strategies. The goal is to understand how AI can optimize charging times and patterns, balancing individual needs with grid requirements. Imagine a user arriving at an EV charging station, here, instead of charging immediately at full power, AI analyses real-time data, including energy prices, grid load, and the user's travel plans, to recommend an optimal charging schedule. Users can follow these suggestions, gaining potential benefits like lower costs or contributing to a greener energy mix by charging when renewable energy is abundant. The demonstrator will also assess user preferences and acceptance of different charging strategies, including trade-offs between charging cost, convenience, and environmental impact.

In addition to the AI-driven user experience, the use case also involves coordinating multiple charging providers (CPOs) on a shared platform, showcasing how various vendors' charging stations can work together seamlessly. This aggregation ensures users can access consistent charging experience across different locations and operators.

The system also connects with the grid operators, both DSOs and TSOs, to offer flexibility services. For example, during peak demand, the grid might signal a need to reduce charging speed or postpone charging. In return, users or charging operators may be compensated for offering this flexibility.

To achieve this coordination and flexibility, the use case will rely on distribution-grid models integrated into the power-system simulation environment, including detailed representations of low-voltage networks where available. This integration enables precise simulation and near-real-time assessment of grid conditions so that the AI-driven charging strategies remain aligned with network capacity and stability needs. By coupling grid models with the simulation framework, we can evaluate alternative charging scenarios, forecast grid impacts, and optimize charging schedules while maintaining balance and flexibility, particularly during peak periods. This approach is critical for accommodating growing EV demand without compromising reliability or efficiency.

The project will demonstrate these features in a lab environment. The goal is to ensure that EV charging infrastructure can scale up without stressing the grid, while also providing a smooth and efficient charging experience for users. Ultimately, this could lead to a more resilient, sustainable, and user-friendly EV ecosystem.

4.9.2. Primary and specialized UCs

The HLUC consists of two Primary Use Cases:

- **PUC9.1 – Real-time Charging Optimization:** focuses on real-time data processing to provide charging recommendations based on grid and user data.
- **PUC9.2 – Grid Flexibility Service Request:** details the communication and execution of flexibility requests from grid operators to adjust charging behaviours.

The Specialized Use Cases defined by the demo sites are:

- **SUC9.1 – Nordic Europe demo.**
- **SUC9.2 – Western Europe demo.**
- **SUC9.3 – Southern Europe demo.**

4.9.3. Technical, economic, and regulatory feasibility

The technical feasibility of HLUC9 rests on capabilities that are already available or rapidly maturing. Real-time data exchange between EVSE, CPO platforms, AI optimizers, and grid operators enables coordinated decision-making across the charging ecosystem. Standardized integration through distribution grid models allows these data streams to be translated into power-system simulations using both closed- and open-source tools, ensuring interoperability and reproducibility. Building on this digital backbone, AI algorithms consider grid operating conditions, dynamic tariffs, and observed user behaviour to optimise charging setpoints. The overall architecture will be tested under diverse grid states and user profiles, validating control logic and coordination strategies against realistic constraints.

From an economic standpoint, the use case offers multiple value levers. For end users, AI-assisted scheduling shifts consumption toward low-price or renewable-rich periods, reducing charging costs. For grid operators, demand-side flexibility mitigates congestion and can defer or avoid expensive network reinforcements. CPOs benefit from coordinated operation that reduces competitive friction, enables bundled service offerings, and supports infrastructure cost-sharing. Because the approach emphasizes software, control, and optimization rather than new hardware, capital expenditure remains limited. Moreover, both CPOs and participating users can unlock new revenue streams by offering flexibility and ancillary services to DSOs/TSOs.

Regulatory feasibility is likewise favourable and broadly aligned with EU policy trends. The Electricity Directive (EU) 2019/944 and Regulation (EU) 2024/1711 promote active consumer participation and the integration of flexible demand, while national and regional smart-grid strategies encourage EV integration and dynamic pricing mechanisms. Remaining challenges are addressable but material: harmonizing communication protocols across heterogeneous

CPO and grid-operator systems; safeguarding data privacy and cybersecurity when sharing behaviour and location-sensitive charging information; and clarifying the legal status and remuneration of aggregators operating in multi-vendor coordination schemes and flexibility markets.

4.10. HLUC10 – Coordinated charging in a virtual power plant setup

4.10.1. Description and scope

This High-Level Use Case focuses on the implementation and testing of coordinated charging in a VPP setup. The virtual power plant consists of a BESS, RESs including wind power and solar photovoltaic, and slow and fast EV chargers, and is intended to facilitate the provision of flexibility services to the distribution system. Accordingly, the objectives are as follows:

1. Review of control and communication infrastructure for VPP.
2. Implementation and testing of control/dispatch algorithms for VPP operation and the delivery of flexibility services.
3. Implementation and testing of autonomous control for the coordination of TSO-DSO grid services.

The use case focuses on the comprehensive review, implementation, and testing of advanced control methods and algorithms designed for the controlled charging of light-duty EVs within a VPP setup. This setup includes both slow and fast chargers, a BESS, and a RES system. The system will be implemented at the Nordic European Demo site in Denmark, at the Risø Campus of the Technical University of Denmark.

The primary objective is to provide flexibility services to the DSO. By integrating these components in the form of a VPP, the system aims to optimize the charging processes, enhance grid stability, and ensure efficient energy management.

The project will explore various strategies to achieve different goals in terms of grid services, as will be defined in WP3 of the AHEAD project. This includes balancing the load, mitigating peak demand, and maximizing the utilization of renewable energy, and other possible services, ultimately contributing to a more sustainable and resilient power grid.

4.10.2. Primary and specialized UCs

The HLUC consists of three Primary Use Cases:

- **PUC10.1 – Investigation of Control Methods for Flexibility Provision via a VPP:** review of control methods for VPP, in the context of a system that combines RESs,

BESS and slow and fast chargers. Understanding best practices for VPP flexibility provision.

- **PUC10.2 – Control/Dispatch Algorithms for VPP Operation:** implementation and thorough testing of control/dispatch algorithms for VPP operation. Evaluation of compliance, results and performance.
- **PUC10.3 – Autonomous Control for TSO-DSO Grid Service Coordination:** implementation and thorough testing of autonomous control for TSO-DSO grid service coordination. Evaluation of compliance, results and performance.

The Specialized Use Cases defined by the demo sites are:

- **SUC10.1 – Nordic Europe demo – Risø campus light-duty EVs with workplace slow charging and highway fast-charging:** the control methods and algorithms for the VPP will be tested at the DTU Risø campus. The end-users of the charging infrastructure are DTU employees and general public.

4.10.3. Technical, economic, and regulatory feasibility

The technical feasibility of HLUC10 is grounded in the integration of controllable EV chargers, a BESS and the RESs (wind and solar photovoltaic). Different EV chargers are used in the use case, where there is a distinguishment between fast and slow chargers. For the latter, different brands are considered in the portfolio. The coordination in a VPP setup requires real-time control and dispatch algorithms on an advanced level. In the demonstration the technical feasibility of control and dispatch for optimal operation is highlighted. Moreover, algorithms for the provision of flexibility services to the distribution system are to be implemented. The presence of a real-world demonstration site with diverse charging infrastructure of different manufacturers, and energy assets allows for robust testing of interoperability and control strategies.

The economic perspective on the HLUC provides significant potential for cost optimization and revenue generation. Alignment of EV charging processes with RES generation as well as storage in the BESS allows for reduction in charging costs. Additionally, extra revenue can be generated from the delivery of flexibility services to the distribution grid. Moreover, the economic viability of HLUC is further enhanced by the fact that software and control are main drivers, contradicting expensive hardware upgrades.

The regulatory feasibility of the HLUC is supported by EU policies, aiming to promote smart charging, demand-side flexibility and the integration of RES, which are essential to the VPP operation. Specifically, the Electricity Directive 2019/944 and 2024/1711 of the EU provide a

legal foundation for demand-side flexibility and active consumer participation. Challenges in terms of regulatory feasibility include the communication standards for the interaction of various hardware components, as well as data security.

4.11. HLUC11 – Activation of flexibility services by distribution system operators

4.11.1. Description and scope

This High-Level Use Case focuses on the activation and management of EV flexibility services within the distribution system by the DSO. It defines how the DSO monitors grid conditions and triggers flexibility measures, through coordinated adjustments in EV charging, to maintain grid stability and optimize energy flows. Accordingly, the objectives are as follows:

1. **Grid Stabilization:** enable the DSO to actively manage load peaks and fluctuations by activating flexibility services.
2. **Optimized Demand Response:** adjust EV charging patterns (e.g., delayed charging, reduced charging rates, or controlled V2G operations) to alleviate grid stress during high-demand periods.
3. **Enhanced Communication:** establish a real-time communication framework between the DSO, charging aggregators, and EV charging stations.

In a modern, smart distribution system, the DSO continuously monitors grid conditions through a combination of sensors and advanced analytics. When the system identifies an impending overload or a rapid change in renewable generation (for example, a sudden drop in wind power), the DSO triggers an activation of flexibility services. Upon detection of the critical grid condition:

1. the DSO issues a flexibility activation command through a secure, real-time communication channel to the EV charging aggregator.
2. The aggregator then disseminates this command to all connected CPOs and, indirectly, to EV users.
3. EV charging stations adjust their charging profiles, this may include delaying the start of a charging session, reducing the charging current, or (if supported) activating V2G discharge.
4. EV users are notified about the change and, if applicable, may receive incentives for their participation.

5. Once the grid condition stabilizes, the system gradually reverts the charging profiles to normal operation and records the performance data for further analysis.

This approach not only supports grid reliability but also provides valuable insights into the responsiveness and potential benefits of demand-side management initiatives within the distribution network. From a business perspective, the workflow puts demand-side flexibility into practice to optimize grid operations, supports the integration of electromobility into smart grids by aligning EV charging with system needs, and delivers cost-effective congestion management at the distribution level through measurable, compensated adjustments.

4.11.2. Primary and specialized UCs

The HLUC consists of three Primary Use Cases:

- **PUC11.1 – Real-Time Grid Monitoring for Flexibility Activation:** focuses on detecting grid stress conditions and triggering flexibility actions.
- **PUC11.2 – Automated Communication of Flexibility Requests:** details the protocols and interfaces for transmitting activation commands from the DSO to the aggregator.
- **PUC11.3 – Feedback and Verification of Activated Flexibility Measures:** covers the collection and analysis of performance data post-activation to confirm the effectiveness of the actions.

The Specialized Use Cases defined by the demo sites are:

- **SUC11.1 – Nordic Europe demo.**
- **SUC11.2 – Western Europe demo.**
- **SUC11.3 – Southern Europe demo.**

4.11.3. Technical, economic, and regulatory feasibility

From a technical standpoint, DSO-led flexibility activation is feasible today because it builds on capabilities already present across the chain: DSO monitoring/forecasting and flexibility activation via IEC 61850-90-8; aggregator/CPO control, telemetry and roaming via IEC 63110 and OCPI 3.0; and EVSE/EV capabilities, including load control and V2G, per ISO 15118-20. The expected growth of distributed generation and EV charging, together with dense urban and industrial distribution infrastructures, makes active power modulation an effective means to relieve local constraints and mitigate congestion.

Economically, establishing a local flexibility procurement model enables deferral of grid reinforcement, lowers congestion-management costs, and creates new value streams for aggregators, charge-point operators, and end users (pay-for-performance with measurable baselines). Costs are concentrated in platform/telemetry integration, software upgrades, and data governance, while benefits accrue through local signals/markets and, where allowed, revenue stacking across services.

On the regulatory side, the European clean-energy framework and aligned national schemes support procurement of local ancillary services from distributed resources, contingent on DSO neutrality, non-discriminatory access for aggregators, transparent settlement, data protection, and cybersecurity. For example, in Italy, regulatory feasibility is strongly supported by ARERA (the national energy regulator) through Deliberation 352/2021/R/eel, which establishes pilot projects for procuring local ancillary services necessary for efficient and safe grid management, in line with European decarbonization targets.

4.12. HLUC12 – Grid planning with artificial intelligence tool

4.12.1. Description and scope

This High-Level Use Case focuses on optimizing the placement of electric vehicle charging stations and improving grid utilization in urban and rural areas through artificial intelligence (AI)-based decision support systems. The system integrates georeferenced data, traffic and mobility patterns, typical charging profiles, and distribution-network hosting capacity with predictive analytics to forecast network loading and charging demand; these forecasts drive a siting module that identifies and ranks optimal charger locations and sizes while explicitly accounting for grid impact and user behaviour. Accordingly, the objectives are as follows:

1. Develop an AI-based decision support system to optimize the location of EV charging stations.
2. Maximize grid utilization by forecasting demand and supply, and balancing energy loads.
3. Use real-time data from EV users, HDVs, vessels, smart meters, and grid operators to continuously improve and adapt AI models.
4. Ensure scalability and reusability of the AI models for different geographic areas and conditions.
5. Provide a clear, georeferenced visualization for stakeholders to make informed planning decisions.

This use case explores the development of an AI-driven decision support system that leverages geospatial data, real-time charging behaviour analysis, and predictive analytics to optimize the deployment of charging infrastructure in a way that maximizes efficiency for both users and the energy grid.

At the core of this system is the integration of spatial mapping models and AI-driven grid forecasting techniques. The process begins with the calibration of spatial mapping models, which incorporate historical charging patterns, georeferenced data, and environmental constraints to identify optimal locations for charging stations. By analysing EV user charging behaviour, HDV fleet movement trends, and vessel shore power requirements, the system pinpoints high-demand areas where new charging stations would provide the greatest benefit. These models undergo continuous refinement, integrating real-time mobility data, urban planning constraints, and energy infrastructure considerations to ensure accurate and dynamic decision-making. In parallel, the system employs grid prediction models to evaluate how newly added charging stations will affect energy distribution and grid performance. These AI-driven models analyse grid load patterns, substation capacity, transformer stress levels, and demand forecasts to determine whether a proposed charging station location is sustainable within the existing energy infrastructure. By simulating different deployment scenarios, the system ensures that new charging infrastructure does not overload the grid but instead optimizes power distribution. Where necessary, it recommends demand-side response strategies, smart charging schedules, or grid reinforcements to maintain energy balance. AI techniques for grid planning are applied to forecast future grid needs, making the system adaptable for long-term planning. The end result is a flexible and scalable solution for deploying EV charging stations, enhancing grid efficiency, and meeting the growing needs of EV users.

4.12.2. Primary and specialized UCs

The HLUC consists of three Primary Use Cases:

- **PUC12.1 – Spatial Mapping Model Calibration for EV Charging Location:** this use case focuses on testing and calibrating spatial mapping models to determine optimal locations for EV charging stations. The model integrates georeferenced data, EV user charging patterns, HDV and vessel charging behaviours, and environmental factors to identify areas with the highest demand for charging infrastructure. By analysing real-world usage patterns, the system fine-tunes its spatial mapping algorithms to ensure the chargers are placed where they are most needed. The goal is to create a more accurate and efficient placement strategy that matches the requirements of both the users and the grid.

- **PUC12.2 – Grid Prediction Model Testing for EV Charging Integration:** this use case involves testing grid prediction models to assess how EV charging stations affect grid performance. The AI-powered models analyse data from existing charging infrastructure, grid loads, and energy demand forecasts to predict how new charging stations will impact the energy grid. The models provide insights into the optimal number and location of charging stations that can be added without overloading the grid, ensuring a balance between energy supply and demand. This predictive analysis helps grid operators and urban planners make informed decisions on EV infrastructure deployment.
- **PUC12.3 – AI Techniques for Grid Planning and Optimization:** in this use case, various AI techniques are applied to optimize grid planning and integration with EV charging stations. The AI models predict future energy needs based on current consumption patterns, charging behaviours, and grid capacity, helping to plan long-term grid expansion and upgrades. These techniques will be tested and validated to ensure that the grid can support the increasing demand for EV charging without compromising stability. The AI-driven planning process focuses on maximizing grid efficiency, minimizing energy waste, and optimizing resource allocation to support both EV users and grid operators.

The Specialized Use Cases defined by the demo sites are:

- **SUC12.1 – Nordic Europe demo.**
- **SUC12.2 – Southern Europe demo.**
- **SUC12.3 – Western Europe demo.**

4.12.3. Technical, economic, and regulatory feasibility

Technically, the solution is built on a modular, lightweight AI architecture tailored for settings with limited and highly imbalanced training data. To ensure robustness and ease of validation, it prioritises interpretable models that deliver transparent, auditable decisions without sacrificing performance. Deployment on Vertex AI provides a scalable, cloud-native environment that simplifies infrastructure management and accelerates the model lifecycle, while the overall design remains cloud-agnostic to avoid vendor lock-in by allowing the substitution of equivalent components as needed. Feasibility in any target area depends critically on data availability: at a minimum, amenity layers, locations and utilisation of existing EV charging stations, and electric-grid structural and load data, supplemented by contextual datasets to enrich features. Absent these mandatory sources, the model cannot be trained or

validated locally; moreover, transferring a model between regions is unlikely to preserve performance due to regional behavioural differences that shape demand for specific charging-site placements. The platform supports multitenancy and fine-grained access control so that only authorised stakeholders (e.g., DSOs, CPOs, municipalities, regulators) can view their respective data and outputs, with role-based permissions enabling differentiated views even within the same organisation. At the same time, the platform ensures transparency and traceability of data processing and AI-generated recommendations for authorised users.. Collectively, these capabilities provide a practical grid-planning tool that can help meet the objectives of the Alternative Fuels Infrastructure Regulation by informing service and infrastructure management. From a DSO perspective, AI-driven siting analysis is a valuable starting point, but it must be grounded in operational realities and data coverage. Recommendations for “ideal” locations should be treated as candidate sites, subject to feasibility checks on land tenure and zoning (e.g., private landowner willingness, municipal constraints or heritage restrictions). Technically, the main risks stem from data gaps: access to external charger locations and utilisation, mobility/traffic flows, and, in some territories, limited visibility of the distribution network topology and loading. Where such inputs are missing or incomplete, model confidence and granularity decline, and results should be surfaced with explicit uncertainty bounds. Mitigations include phased data-sharing agreements or proxy datasets, progressive enhancement of network models, and continuous calibration with measured outcomes. In this configuration, the tool supports the DSO by generating defensible, ranked options that can be integrated with planning rules, connection studies, and stakeholder engagement, rather than purporting to deliver a single “correct” answer.

Economically, the implementation is not merely a showcase of AI for EV charging; it is a decision-support tool for infrastructure owners and service providers. It can guide when and where to add, relocate, or decommission charging points while monitoring grid conditions to prevent incidents and unwanted service interruptions. Because the platform is reusable across different territories and scenarios, it scales operationally; however, users should expect model outputs to vary with local data coverage and quality, which remain the dominant determinants of accuracy and business value. From a DSO perspective, the business case is sensitive to data-access costs and variability. High-resolution mobility datasets (e.g., historical traffic from telecom or global positioning system (GPS) providers) can be expensive and, in some regions, unavailable, introducing both direct Opex for data licensing and uncertainty in benefit estimates.

From a regulatory standpoint, the principal data sources are aggregated and anonymised: EV-station utilisation and grid-load measurements are processed into cumulative indicators over sub-areas and do not contain session-level or customer-identifying information. This privacy-by-design approach supports compliance with the EU AI Act (including transparency and risk-management expectations) and with GDPR requirements for data minimisation, lawful processing, and access control. From a DSO perspective, confidentiality requirements vary by data source and network context. Where end-consumer load data are involved, they must be properly aggregated and anonymised so individual consumption patterns cannot be re-identified under GDPR. This is challenging on “thin” networks, e.g., an MV/LV substation or MV feeder serving a single industrial customer or very few premises, where small-N aggregation may still expose identities. In such cases, the analysis should be disabled or redesigned to preserve compliance. Similar caution applies to privately owned or access-restricted charging stations, where location and utilisation data may be commercially sensitive or indirectly identifying.

REFERENCES

- [1] IEC International Standard, 2015. 62559-2:2015 Use case methodology - Part 2: Definition of the templates for use cases, actor list and requirements list.

I. ANNEX – DESCRIPTION OF THE USE CASE TEMPLATE

In the IEC 62559-2 framework, a Use Case is a structured description of how a system is expected to behave in interaction with external actors. Actors can be human users, external systems, or other entities that play a role within the scenario. Depending on the degree of abstraction and detail, use cases can be classified into different levels:

- High-Level Use Case (HLUC): a use case defined at a conceptual level, capturing general requirements, needs, or ideas without reference to a specific technical implementation or system architecture.
- Primary Use Case (PUC): a more detailed description of the functionality, often corresponding to the steps or tasks of a business process, but still independent from concrete technological solutions.
- Specialized Use Case (SUC): a use case refined towards implementation, where specific technical choices, architectures, or pilot configurations are described. This type of use case is linked to particular technologies and solutions and thus provides details only relevant in specific contexts.

I.1 Description of the Use Case

I.1.1 Name of the use case

<i>Use case identification</i>		
<i>ID</i>	<i>Area/Domain(s)/Zone(s)</i>	<i>Name of use case</i>
Each use case is assigned a unique identification number within the repository or project. This identifier facilitates the structured organization and administration of use cases. For high-level use cases, the recommended syntax is: HLUCXX	Use cases can be used in various areas. Within these areas, different domains are used to define/determine a more specific subgrouping.	The names of the use cases were assigned during the proposal phase.

I.I.II Version management

Version No.	Date	Name of author(s)	Changes
0.0	05.09.24	Marzio Barresi	First template provided
(0.1, 0.2, 0.V)	DD.MM.YY	Name	Draft update of HLUC
1.0	DD.MM.YY	Name	Final version of HLUC

I.I.III Scope and objectives of use case

Scope and objectives of use case	
Scope	The scope defines the limits of the use case.
Objective(s)	List of objectives of the use case

I.I.IV Narrative of use case

Narrative of use case
Short description
This part provides a concise summary of the use case, capturing its main purpose and key idea. It serves as a quick reference for readers who are scanning several use cases or seeking an initial overview.
Complete description
This part presents a detailed narrative of the use case from the user's perspective. It explains what actions take place, the underlying reasons, the expected outcomes, and the conditions under which the scenario unfolds. The text should be written in a clear and non-technical manner, ensuring that it is understandable even for readers who are not domain experts. Depending on the complexity of the use case, this description may vary in length from a few paragraphs to several pages.
In addition to providing clarity for a broader audience, this section also supports domain experts in identifying and refining user requirements before addressing the more technical details that follow in the template.

I.I.V Related primary use cases

ID	Name	Description
For primary use cases, the recommended syntax is: PUCX.Y	Include primary use case name	Describes a specific functionality derived from a High-Level Use Case, outlining its scope, objectives, and distinctive features within the overall process.

I.I.VI Related specialized use cases

ID	Name	Description
For specialized use cases, the recommended syntax is: SUCX.W	Include specialized use case name.	Represents the implementation of a use case in a specific demo site, detailing the applied technology, local conditions, and context-specific characteristics.

I.I.VII Key performance indicators (KPI)

Key performance indicators			
ID	Name	Description	Reference to mentioned use case objectives
Unique identifier for the Key Performance Indicator. The recommended syntax is: KPIX.M	Short name that describes the KPI.	The description specifies the KPI and may include specific targets in relation to one of the objectives of the use case and the calculation of these targets.	Here is the link to one of the objectives which are specified in the targets and the KPI before.

I.I.VIII Use case conditions

Use case conditions
Assumptions May be used to define further, general assumption for this use case. In some use cases, it is critical to understand which preconditions or other assumptions are being made. - Any assumptions shall be identified, such as which systems already exist, which contractual relations exist, and which configurations of systems are probably in place. - Any initial states of information exchanged in the steps in the next section shall be identified.
Prerequisites Describes what condition(s) should have been met prior to the initiation of the use case, such as prior state of the actors and activities.

I.I.IX Further information to the use case for classification/mapping

Classification information
Relation to other use cases This section can be used to indicate links with other use cases. For example, it may show when a use case represents a more detailed instance of a High-Level Use Case, or when it provides an alternative to an existing one. It can also include the IDs of related AHEAD use cases.
Level of depth Defines the level of depth of the use case: - High-level use case (HLUCX) - Primary use case (PUCX.Y) - Specialized use case (SUCX.W)
Prioritisation Considering a larger number of use cases it might be interesting to cluster them according to priority. This prioritisation might be different from country to country.
Generic, regional or national relation <u>Generic, regional or national relation</u> : On international level, the use case description might be generic enough to describe a use case in a more general way independently from the national or regional market design. But use cases might be used to describe regional or national specific circumstances like laws or even project-specific details. If the use case reflects those circumstances, it should be characterized accordingly.
Nature of the use case

This field can help to classify the main focus of the use case. EXAMPLE: Technical/system use case, business use cases (e.g. market processes), political, test use cases.
Further keywords for classification
Keywords can be defined in order to support extended search functionalities within a use case repository. Multiple keywords should be provided as a comma-separated list. EXAMPLE: Smart grid, electric vehicles, loading of vehicles, electricity metering, storage.

I.II Diagram of use case

Diagram(s) of use case	
	Insert Use Case diagram here

I.III Technical details

I.III.I Actors

Actors			
Grouping		Group description	
The actor list can be grouped in order to provide a better overview and retrieval using one table per “grouping”		Brief description of the group.	
Actor name	Actor type	Actor description	Further information specific to this use case
The specific role, system, or entity participating in the use case. Actor names should be concise and unambiguous.	Identifies whether the actor is a human role (e.g., consumer, operator, planner) or a non-human entity such as software, systems, applications, devices, or external organizations.	A short explanation of what the actor does in the context of the use case. This should describe its function, responsibility, and how it contributes to the use case scenario.	Additional context that is directly relevant to the specific use case being described. This can include concrete examples, particular datasets, constraints, or site-specific information that clarifies how the actor's role is realized in practice.

References

No.	References type	Reference	Status	Impact on use case	Originator/organization	Link
Sequential identifier used for in-text citations. The recommended syntax is RX.N, where X is the use-case number and N is a sequential integer within that use case.	Category of the source, such as Regulation, Standard, Contract, Policy, Technical Report, Publication, Market Rules, Grid Code, or Other.	Exact title and/or identifier of the document	Current state of the document (e.g., Valid, In force since <date>, Draft, Under review)	Short, concrete note on where and how the reference influences this use case.	Authoring or issuing body	If available, a public link can be provided

I.IV Step by step analysis of use case

This section outlines the scenarios of the use case through a step-by-step sequence description. Each step should maintain a clear link with the overall narrative, ensuring consistency between the general description and the detailed scenarios.

I.IV.I Overview of scenarios

The table provides an overview of the different scenarios of the use case like normal and alternative scenarios which are described in the following section.

Scenario conditions						
No.	Scenario name	Scenario description	Primary actor	Triggering event	Pre-condition	Post-condition
The scenarios are sequentially numbered	Indicate a unique name for the scenario.	Describe shortly the scenario.	Refers to the actor that triggers the scenario.	Indicate the event that will trigger the scenario.	Describes which condition(s) should have been met before this scenario happens.	Describes which condition(s) should prevail after this scenario happens. The post conditions may also define “success” or “failure” conditions for each use case.

I.IV.II Steps – Scenarios

Scenario	
Scenario name:	No. 1 - ...

Step No.	Event	Name of process/ activity	Description of process/ activity	Service	Information producer (actor)	Information receiver (actor)	Information exchanged (IDs)
A sequential number that identifies each step. The recommended syntax is S.J, where S is the scenario number and J is the step number.	The event that triggers the step. This might be completion of the previous step.	Label that would appear in a process diagram. Action verbs should be used when naming activity. EXAMPLE: "Fault occurs in the grid".	This describes what action takes place in this step. The focus should be less on the algorithms of the applications and more on the interactions and information flows between actors.	This column identifies the nature of the information flow and the originator of the information. (*).	This identifies the producer or source of the information. This should correspond to one of the actors defined in the use case.	This identifies the receiver of the information. This should also correspond to one of the actors identified for the use case.	A reference to the information exchanged between the two actors. Only the ID is listed here, which corresponds to the "Information Exchanged" table where the detailed description is provided.

(*) Available options are:

- CREATE means that an information object is to be created at the Producer.
- GET (this is the default value if none is populated) means that the Receiver requests information from the Producer (default).
- CHANGE means that information is to be updated. Producer updates the Receiver's information.
- DELETE means that information is to be deleted. Producer deletes information from the Receiver.
- CANCEL, CLOSE imply actions related to processes, such as the closure of a work order or the cancellation of a control request.
- EXECUTE is used when a complex transaction is being conveyed using a service, which potentially contains more than one verb.
- REPORT is used to represent transferral of unsolicited information or asynchronous information flows. Producer provides information to the Receiver.
- TIMER is used to represent a waiting period. When using the TIMER service, the Information Producer and Information Receiver fields shall refer to the same actor.

- REPEAT is used to indicate that a series of steps is repeated until a condition or trigger event. The condition is specified as the text in the “Event” column for this row or step. Following the word REPEAT, shall appear, in parenthesis, the first and last step numbers of the series to be repeated in the following form REPEAT(X-Y) where X is the first step and Y is the last step.

I.V Information exchanged

Information exchanged, ID	Name of information	Description of information exchanged
A unique identifier that corresponds to the entry listed in the column “Information Exchanged (IDs)” of the Steps – Scenarios table. The recommended syntax is IE-S.K, where S is the scenario number in which the information first appears, and K is a sequential counter.	A short and clear label that describes the information exchanged	A concise explanation of the content, purpose, and context of the information. Where possible, references to existing data models, standards, or information classes should be included. The use of canonical and standardized data models is recommended to ensure interoperability.

I.VI Common terms and definitions

Common terms and definitions	
Term	Definition
Relevant terms belonging to this use case are listed	Provide their corresponding definitions.

II. ANNEX – COMPLETE DESCRIPTION OF AHEAD USE CASES

II.I HLUC1 – New demand response and flexibility contracts

Description of the use case

Name of the use case

Use case identification		
ID	Area/Domain(s)/Zone(s)	Name of use case
HLUC1	Area: energy system Domain: distribution System Zones: operation, station, field	New demand response and flexibility contracts

Version management

Version management			
Version No.	Date	Name of author(s)	Changes
0.0	05.09.24	Marzio Barresi (POLIMI)	First template provided
0.1	20.12.24	Kristian Sevdari (DTU)	First draft of HLUC1
0.2	02.06.25	Kristian Sevdari (DTU)	Second draft of HLUC1
0.3	22.10.25	Marzio Barresi (POLIMI)	Final draft version of HLUC1

Scope and objectives of use case

Scope and objectives of use case	
Scope	This High-Level Use Case (HLUC) addresses the evaluation and implementation of innovative demand response (DR) programs and flexibility contracts for electric vehicle (EV) users and aggregators. The purpose is to ensure optimal integration of EVs into the electricity grid by aligning EV charging behaviour with distribution system operator (DSO) and transmission system operator (TSO) grid stability requirements. The testing spans across various e-mobility contexts, including urban, rural, maritime, and inter-urban transport scenarios. The HLUC consists of three Primary Use Cases (PUCs): • PUC1.1 – Viable Flexibility Grid Services from EVs: investigating existing and potential flexibility services leveraging EVs to support grid stability, voltage control, frequency regulation, and renewable energy integration. • PUC1.2 – DSO-TSO Coordination and Flexibility Capacity Markets: exploring flexible capacity contracts, conditional capacity agreements, and coordination frameworks between DSOs and TSOs, ensuring that flexibility services from EVs are aligned with operational constraints and market opportunities.

	• PUC1.3 – Economic Feasibility and User Comfort: evaluating user acceptance, economic viability, and user comfort implications of smart charging programs guided by artificial intelligence (AI)-driven optimization tools, including dynamic pricing and real-time market participation. The Specialized Use Cases (SUCs) defined by the demo sites are: • SUC1.1 – Nordic Europe Demo: addresses flexibility from workplace charging and fast highway charging infrastructure, considering renewable energy integration and battery storage. • SUC1.2 – Southern Europe Demo (Milan/Kranj): focuses on flexibility services associated with electric bus depot charging operations. • SUC1.3 – Western Europe Demo (Lisbon and Funchal): evaluates DR and flexibility services involving vessel charging and wireless EV charging systems.
Objective(s)	1. Review and analyse existing DSO and TSO grid flexibility services. 2. Simulate and assess EV grid service provision scenarios for technical and economic feasibility. 3. Develop decision-making algorithms to optimize EV flexibility offerings across diverse operational scenarios. 4. Conduct surveys and analysis of user responses and comfort levels regarding participation in DR programs and flexibility contracts.

Narrative of use case

Narrative of use case	
Short description	
This use case is aimed at testing demand management programs. This includes three different topics: 1) Viable flexibility grid services from EVs. 2) Coordination of DSO-TSO and flexibility capacity markets. 3) Investigation of economic feasibility and comfort for users. Altogether, the objective of this use case is to shed some light in these areas that are currently starting to be explored. Furthermore, this use case is interconnected with all other use cases.	
Complete description	
1. Review of flexibility services: building on references from the project proposal, HLUC5 (workplace charging scenarios), HLUC8 (port charging scenarios), and HLUC11 (DSO-led flexibility services), the project team compiles a comprehensive set of EV-based flexibility services, analysing technical, regulatory, and economic drivers. 2. Simulation and prototyping: Various DR strategies are simulated to test how EV charging can align with grid stability needs (voltage, frequency) and reduce peak load. This step uses real-time data and AI-based forecasting, continuing the synergy of WP3–WP4 from the project proposal. 3. Implementation in specialized demos: The strategies are rolled out in three specialized demos: ○ SUC1.1 (Nordic Europe demo): slow/fast charging synergy (UC5), exploring aggregator-based DR programs in a semi-rural environment. ○ SUC1.2 (Milan/Kranj): electric bus depot synergy with DSO-led flexibility (UC11), evaluating capacity constraints and DR incentives. ○ SUC1.3 (Lisbon/Funchal): vessel charging synergy (UC8) + wireless charging. Focus: synergy with maritime tourist vessels, dynamic pricing. 4. User acceptance and economic viability: Surveys, interviews, and performance metrics ascertain user willingness to adapt charging schedules for cost savings, climate impact, or grid support. 5. Dissemination of results: Publications and best-practices guidelines developed, including new contract templates for DSOs/TSOs and aggregator negotiations.	

Related primary use case

ID	Name	Description
PUC1.1	Viable Flexibility Grid Services from EVs.	Review of existing grid services and applicability in the European context. Understanding the best practices and feasibility with the country grid conditions. Exploiting the expertise and experience of the consortium members from DSOs, TSOs and research environment. Finally, filtering the research on e-mobility domain.
PUC1.2	DSO-TSO Coordination and Flexibility Capacity Markets	Understanding how to implement flexibility services that do not harm the DSO or TSO. For example, a solution to be tested is the implementation of conditional capacity agreements with the DSO and providing frequency services with the TSO.
PUC1.3	Economic Feasibility and User Comfort	Simulation and forecasting with AI tools of smart charging programs for end users following the spot market, time of use tariffs and the possibility of entering balancing markets. Also, understanding if such smart charging algorithms compromise the user comfort and their participation.

Related specialized use case

ID	Name
SUC1.1	Nordic Europe demo – Slow/fast charging demo (light-duty EVs with workplace charging and highway fast charging)
SUC1.2	Southern Europe demo – Mian and Kranj (electric bus and depot charging)
SUC1.3	Western Europe demo – Lisbon and Funchal (vessel charging and EV wireless charging)

Key performance indicators (KPI)

Key performance indicators			
ID	Name	Description	Reference to mentioned use case objectives
PUC1.1			
KPI1.1	Review of flexibility services for e-mobility applications	Publication on the flexibility services good practices in Europe.	Objective 1
PUC1.2			
KPI1.2	Demonstration of conditional capacity agreement and frequency service delivery in the demos	Technical demonstration in demos.	Objective 2,3,4
PUC1.3			
KPI1.3	Economic benefits	Publication on the calculating the economic benefits from flexibility services in the demos.	Objective 4

Use case conditions

Use case conditions
Assumptions

A sufficient number of EV users and charging stations are available at demo sites.
EV arrivals and charging needs are variable and not fully predictable.
Local grid capacity is limited, creating conditions for congestion and flexibility needs.
A share of EV users is willing to participate in DR programs if provided with clear incentives.
Communication protocols between electric vehicle supply equipment (EVSE), aggregators, DSOs and TSOs are interoperable and functional.
Prerequisites
Smart charging algorithms are available to optimize charging under grid and market constraints.
Charging stations at demo sites support remote power control and communication.
The charging site has multiple outlets.
Historical and real-time data on charging profiles and grid conditions are accessible.

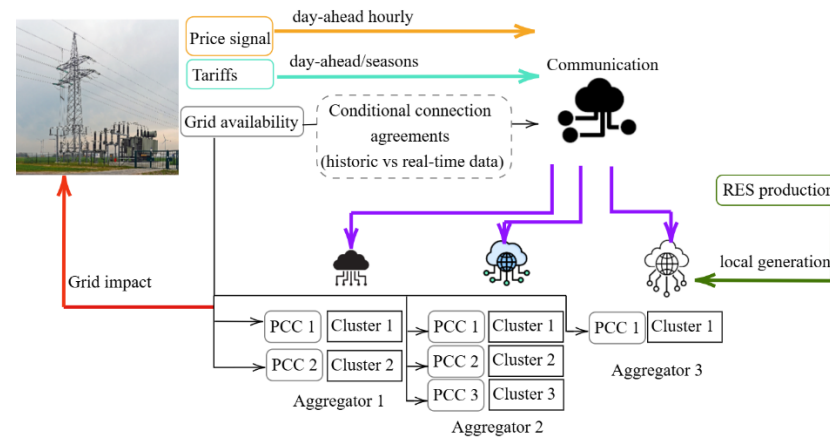
[Further information to the use case for classification/mapping](#)

Classification information
Relation to other use cases
• Relation to other UCs: This HLUC strongly relates to HLUC5 (smart charging in workplaces), HLUC8 (smart charging in ports), HLUC11 (DSO activation of flexibility services), and potentially HLUC9/HLUC10 (coordinated charging).
Level of depth
HLUC1 – New demand response and flexibility contracts • PUC1.1 – Investigation of viable flexibility grid services from EVs. • PUC1.2 – Investigation of DSO-TSO coordination and flexibility capacity markets. • PUC1.3 – Investigation of economic feasibility and comfort for users. ▪ SUC1.1 – Nordic Europe demo – Slow/fast charging demo (light-duty EVs with workplace charging and highway fast charging) ▪ SUC1.2 – Southern Europe demo – Milan/Kranj (electric bus and depot charging) ▪ SUC1.3 – Western Europe demo – Lisbon and Funchal (vessel charging and EV wireless charging)
Prioritisation
High priority for AHEAD since this use case has regulatory, technical and business relevance.
Generic, regional or national relation
Regulatory and business perspective can be affected by national/regional environment.
Nature of the use case
Both simulation-based (AI algorithms, forecasting) and practical demonstration-based (demonstrators in WP7–WP9).
Further keywords for classification
Flexibility services, smart charging, AI system management

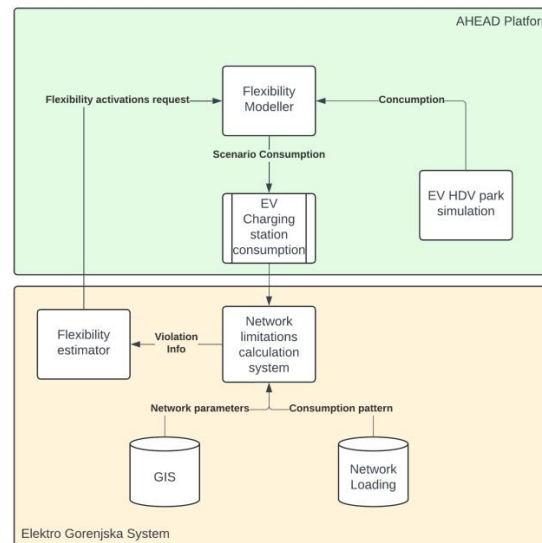
Diagram of use case

Diagram(s) of use case

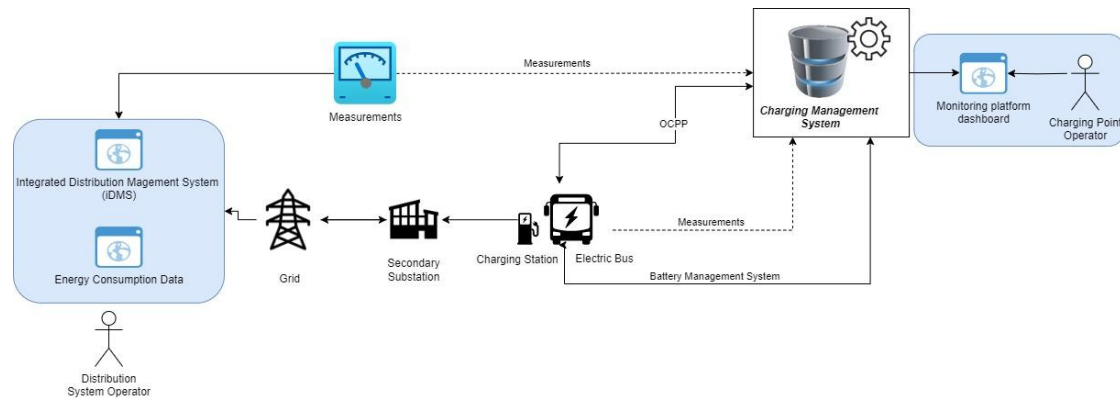
SUC1.1: Nordic Europe demo



SUC1.2: Southern Europe demo (Kranj)

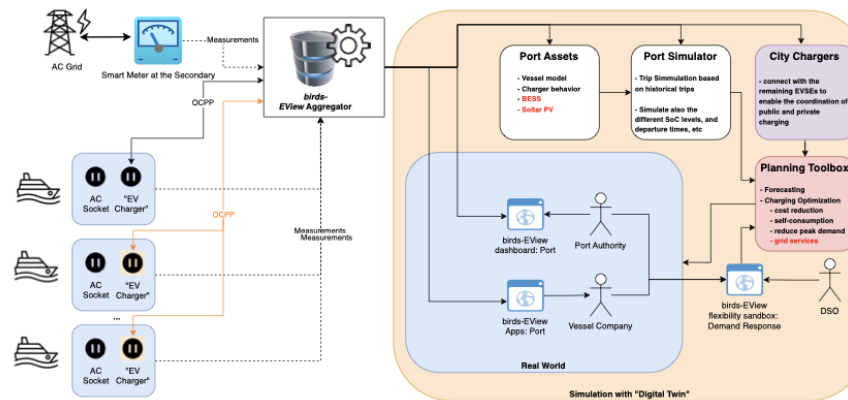


SUC1.3: Southern Europe demo (Milan)

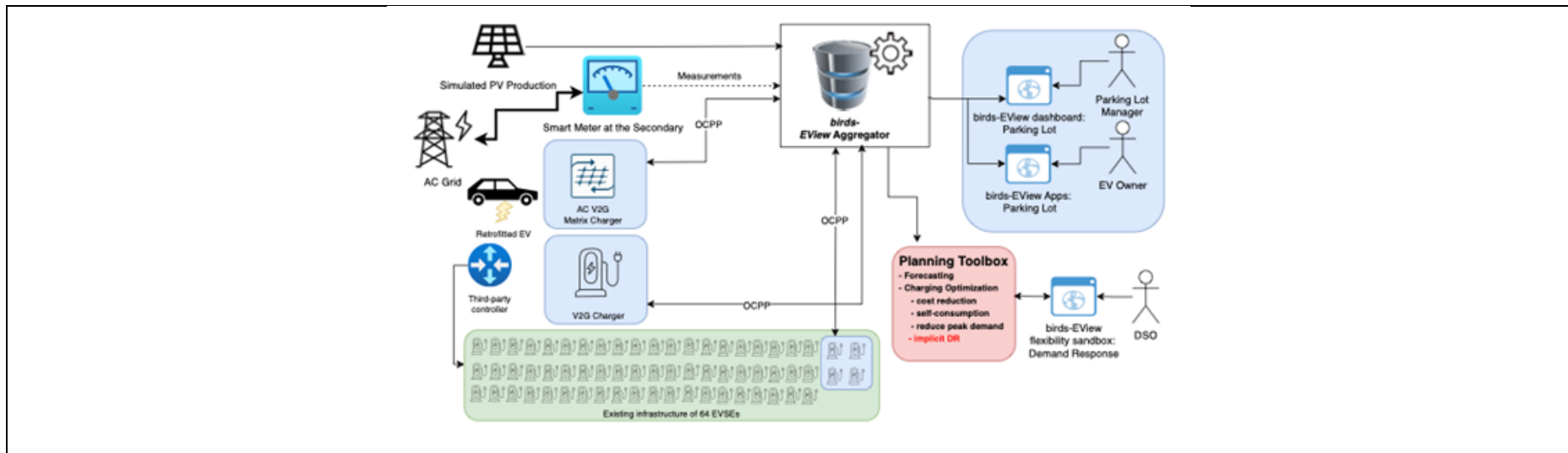


SUC1.3: Western Europe demo

Vessel Charging in Maritime-Touristic Activities



Wireless Charging in parking lots



Technical details

Actors

Actors			
Grouping		Group description	
Flexibility services from EVs		This group includes human actors for the use cases related to different types of flexibility.	
Actor name	Actor type	Actor description	Further information specific to this use case
Distribution System Operator	Business Actor	Monitors and manages the distribution grid. Activates or requests flexibility services from EV aggregators.	Critical for local grid stability, synergy with UC11.
Transmission System Operator	Business Actor	Oversees high-voltage grid operation, can contract aggregator for frequency regulation, balancing.	Coordinates with DSOs to avoid contradictory control signals.
Electric Vehicle Owners/Users	Human Actor	Participants providing flexibility by adjusting or delaying charging.	Comfort & acceptance measured, synergy with UC5.
Aggregator	Logical Actor	Pools EV resources and executes DR/flexibility schedules on behalf of DSOs/TSOs.	Key enabler for combined DSO–TSO market coordination.

Smart Charging Management System (SCMS)	System/Software Actor	Automates scheduling, synergy with aggregator, ensures AI-based optimization.	Receives signals from aggregator and DSO/TSO, synergy with UC5 & UC8.
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Step-by-step analysis of use case

Overview of scenarios

Scenario conditions						
No.	Scenario name	Scenario description	Primary actor	Triggering event	Pre-condition	Post-condition
1	Uncoordinated Charging Scenario	EV arrives and immediately starts charging without any grid coordination, possibly causing peak loads and local congestion.	EV User	EV user plugs in the vehicle	Charging station operational, EV needs charging	EV charges at full rate, potential grid stress or higher peak loads
2	Optimized Smart Charging Scenario	EV arrives, aggregator or Smart Charging System schedules it using predictive algorithms (considering grid constraints, dynamic prices, etc.).	Aggregator/SCMS	EV user requests charging, aggregator sees event	Aggregator platform, real-time data feeds from the grid, user acceptance	EV charges based on an optimized schedule, balancing grid load, user costs, and comfort
3	Flexibility Service Scenario	DSO or TSO signals a request for load reduction or shift. Aggregator adjusts EV charging rates accordingly to meet grid demands.	DSO/TSO	Detection of grid stress or market signal	Communication protocol established among aggregator, DSO, TSO, and EV stations	EV charging is modulated to alleviate grid stress or provide balancing/ancillary services

Steps-scenarios

Scenario							
Scenario name:		No. 1 - Uncoordinated Charging Scenario					
Step No.	Event	Name of process/activity	Description of process/activity	Service	Information producer (actor)	Information receiver (actor)	Information exchanged (IDs)
1.1	EV arrives at station	EV Arrival Notification	Vehicle owner parks and connects EV at the charging infrastructure.	REPORT	EV Owner/User	Aggregator	IE-1.1
1.2	Charging starts	Uncoordinated Charging	Charging begins immediately without optimization.	EXECUTE	EV Owner/User	SCMS	IE-1.2

Scenario							
Scenario name:		No. 2 - Optimized Smart Charging Scenario					
Step No.	Event	Name of process/activity	Description of process/activity	Service	Information producer (actor)	Information receiver (actor)	Information exchanged (IDs)
2.1	EV arrives at station	EV Arrival Notification	Vehicle owner parks and connects EV at the charging infrastructure.	REPORT	EV Owner/User	Aggregator	IE-2.1
2.2	Charging request sent	Charging Request Submission	EV user provides charging needs (state-of-charge, preferences, departure time).	CREATE	EV Owner/User	Aggregator	IE-2.2
2.3	Optimization request received	Optimization Request	Aggregator requests an optimized charging plan from SCMS.	GET	Aggregator	SCMS	IE-2.3
2.4	Schedule calculated	Charging Schedule Optimization	SCMS generates an optimized charging schedule.	CREATE	SCMS	Aggregator	IE-2.4
2.5	Charging executed	Smart Charging Execution	Aggregator instructs SCMS to apply optimized charging profile.	EXECUTE	Aggregator	SCMS	IE-2.5

Scenario							
Scenario name:		No. 3 - Flexibility Service Scenario					
Step No.	Event	Name of process/activity	Description of process/activity	Service	Information producer (actor)	Information receiver (actor)	Information exchanged (IDs)
3.1	EV already charging	EV Charging in Progress	SCMS reports ongoing charging session to Aggregator.	REPORT	SCMS	Aggregator	IE-3.1

3.2	Grid stress detected	Flexibility Request	DSO/TSO sends request for load reduction or shift to Aggregator.	CREATE	DSO / TSO	Aggregator	IE-3.2
3.3	Adjustment triggered	Flexibility Activation	Aggregator commands SCMS to adapt charging profile.	CHANGE	Aggregator	SCMS	IE-3.3
3.4	Adjusted schedule applied	Charging Schedule Adaptation	SCMS updates charging profile accordingly.	CHANGE	SCMS	EV Owner/User	IE-3.4
3.5	Grid service delivered	Flexibility Service Execution	EV charging adapts to provide flexibility, user experiences updated behaviour.	EXECUTE	SCMS	DSO/TSO	IE-3.5

Information exchanged

<i>Information exchanged</i>		
<i>Information exchanged, ID</i>	<i>Name of information</i>	<i>Description of information exchanged</i>
IE-1.1	EV Arrival Notification	Notification that EV is plugged in and ready to charge.
IE-1.2	Uncoordinated Charging Start	Charging begins immediately without optimization.
IE-2.1	EV Arrival Notification	EV connection reported to aggregator.
IE-2.2	Charging Request Submission	EV user provides state-of-charge, preferences, and departure time.
IE-2.3	Optimization Request	Aggregator requests optimal charging plan.
IE-2.4	Optimized Charging Schedule	SCMS provides optimized charging schedule
IE-2.5	Smart Charging Execution Command	Aggregator instructs SCMS to apply optimized charging schedule.
IE-3.1	Charging Status Report	Ongoing charging session status.
IE-3.2	Flexibility Request	Request for load reduction/shift.
IE-3.3	Flexibility Activation Command	Aggregator instructs SCMS to adjust charging.
IE-3.4	Adjusted Charging Schedule	SCMS communicates new charging profile to user (implicitly through EV).
IE-3.5	Flexibility Service Execution	Adjusted charging executed and reported as flexibility service delivered to grid operator.

Common terms and definitions

<i>Common terms and definitions</i>	
<i>Term</i>	<i>Definition</i>
Aggregator	Entity combining multiple distributed flexibility resources to offer grid support services.

AI	Artificial intelligence
BESS	Battery energy storage system
Demand Response	Adjustment of electricity usage by end-users in response to grid conditions and economic incentives.
DSO	Distribution system operator
EMS	Energy management system
EV	Electric vehicle
EVSE	Electric vehicle supply equipment
Flexibility Contracts	Agreements specifying terms for flexibility provision to grid operators.
HLUC	High-level use case
PUC	Primary use case
RES	Renewable energy sources
SCMS	Smart charging management system
Smart Charging	Dynamic management of EV charging to align with grid requirements and economic signals.
SUC	Specialized use case
TSO	Transmission system operator

II.II HLUC2 – Charging station with low-rated capacity

Description of the use case

Name of the use case

Use case identification		
ID	Area/Domain(s)/Zone(s)	Name of use case
HLUC2	Electric Vehicle Charging, Smart Grid, Energy Management	Charging stations with low-rated capacity

Version management

Version management			
Version No.	Date	Name of author(s)	Changes
0.0	05.09.24	Marzio Barresi (POLIMI)	First template provided
0.1	07.05.25	Tommaso Reschiglian (DTU)	First draft of HLUC2
0.2	22.05.25	Tommaso Reschiglian (DTU)	Second draft of HLUC2
0.3	22.10.25	Marzio Barresi (POLIMI)	Final draft version of HLUC2

Scope and objectives of use case

Scope and objectives of use case	
Scope	The High-Level Use Case (HLUC) focuses on optimizing electric vehicle (EV) charging station with low rated capacity by integrating renewable energy sources (RES) and battery energy storage systems (BESS). This is applied in both DC and AC charging stations and aims to create a control algorithm to managing the power distribution. Three primary use cases (PUCs) that will be developed: • PUC2.1 – Investigate power sharing algorithm to increase the efficiency of the available power. Scope: Optimization of energy resources • PUC2.2 – Investigate power sharing algorithm to increase the efficiency of the operation for multi-outlet chargers. Scope: Optimizing power distribution across multiple charging ports • PUC2.3 – Scheduling vs modulation control algorithm for managing EV charging station. Scope: Evaluate the performance of a charging station utilizing BESS and RES Three specialized use cases (SUCs) will be developed according to the demos. • SUC2.1- Nordic Europe demo slow/fast charging demo (light-duty EVs with workplace charging and highway fast charging): both locations will implement smart management of the available power, requesting only 22% (Location 1 – fast charging demo) and 32% (Location 2 – slow charging demo) of the total available capacity.

	- SUC2.2 Southern Europe demo: this demo explores the flexibility potential of both private and public EV fleets integrated into the grid. In Slovenia (Kranj), planning tools will be tested, and flexibility services will be simulated based on a charging park that is not yet operational. In Italy (Milan), real-world data from a charging hub with 96 V1G points serving a utility fleet operated by A2A will be used to simulate control strategies for power management and to evaluate the impact of temporal charging patterns. - SUC2.3 Western Europe demo: Pilots 1 and 3 will utilize smart management of available power. Both cases will consider charging in parking lots and management of multiple sockets. The main distinction is the scale and duration of parking. Location 1 is a residential garage with capacity for four electric vehicle supply equipment (EVSEs), but only two are currently available. Charging here is mostly during weekends or nighttime during the week. In contrast, location 2 is a semi-public parking lot that is mostly used by professionals during the day. I.e., parking is mostly during weekdays and during working hours.
Objective(s)	1) Develop a smart management algorithm to optimize power usage 2) Testing the integration of BESS and RES to optimize EV charging efficiency 3) Optimizing power quality

Narrative of use case

Narrative of use case	
Short description	This use case examines the smart management of electric vehicle (EV) charging stations that operate with limited grid capacity. By implementing optimization algorithms for power consumption and multi-outlet charging, the system achieves efficient charging, reduces dependence on the grid, and enhances flexibility in services. All of this is accomplished while maintaining cost-effectiveness and reliability.
Complete description	Imagine a typical day at a busy electric vehicle (EV) charging station located in an urban area. The station supports multiple EVs at the same time but is connected to the power grid with limited capacity. This limitation makes it impossible to fast-charge all connected vehicles simultaneously using only grid power. To tackle this, the charging station uses a smart management system that makes real-time decisions about how and when to deliver power to vehicles. The system includes a local energy storage battery and multiple charging outlets. It also has software that uses optimization algorithms to control how power is distributed across the station. From a user's point of view, the process is seamless. A driver arrives, plugs in their EV, and expects it to be charged within a reasonable amount of time. They may not realize that behind the scenes, the station is dynamically deciding how to balance power between several vehicles, possibly using stored battery energy when grid power is insufficient. For example, if three vehicles arrive around the same time, the system checks current grid availability, the energy stored in the battery, and the expected departure times of each vehicle. Based on this, it may decide to fast-charge one vehicle first using the battery, then gradually charge the others when grid demand is lower. This ensures that each vehicle receives the energy it needs without overloading the grid or causing unnecessary delays. In addition, the charging strategy can incorporate demand-response signals or flexibility requests from the DSO to shift charging demand away from peak periods and support grid stability. The expectation is that users receive reliable, efficient charging without having to worry about the technical challenges of energy management. At the same time, the operator of the station benefits from lower energy costs (e.g., by avoiding peak-hour grid usage), better use of local battery storage, and the ability to serve more vehicles without needing an expensive grid upgrade. This use case demonstrates how smart energy management not only supports the growth of EV infrastructure but also improves user experience and system sustainability. It reflects a shift from simple plug-and-charge models to intelligent systems that coordinate multiple resources under real-world constraints. Nordic Europe demo The demo will focus on workplace and highway charging under limited grid capacity. Smart management algorithms will be tested to ensure reliable service, while real-world scenarios with different utilization rates (22% and 32% of available power) will be simulated to evaluate the benefits of BESS and RES integration. Southern Europe Demo Southern Europe demo focuses on checking the feasibility of charging of both the private and the public transport electric vehicles and the quantity the flexibility which can be provided by their integration into the grid. Two locations are selected to better investigate novel approaches for the operation of the charging stations in different approaches.

This will be facilitated thanks to the cooperation with A2A, EG (distribution system operator (DSO) in Kranj, Slovenia), UNR (DSO in Milan, Italy), ATM (public transportation operator in Milan, Italy), POLIMI, and KEMPOWER.

In Slovenia, planning tools will be tested to appropriately prepare the grid. In addition, we will simulate flexibility services provided by the charging park, based on a real-world facility that is not yet operational.

In Italy, the test site is located in Milan, at a charging hub integrated within a primary high voltage (HV)/medium voltage (MV) substation. The site features 96 V1G charging points, primarily used by light-duty EVs from A2A. The pilot will focus on collecting real-world charging data from the entire EV fleet. These data will then be used in simulations to analyse different control strategies for power management, with the objective of improving system efficiency, reducing peak demand, and maximizing the integration of RES and BESS. Particular attention will be paid to the impact of temporal charging patterns and flexibility potential, leveraging the large number of available chargers and the controlled environment of the fleet.

Western Europe Demo – Location 1

Location 1 in the Western Europe Demo is a garage that is shared by four families that live in the same building, in Funchal. The garage has space for four cars, from which two are currently EVs. A particularly relevant aspect of this UC is that the garage has its own power contract – currently a 6.9 kVA.

For this demo, a multioutlet EVSE with V1G capabilities will be installed and the main objective is to ensure that the charging never exceeds the contracted 6.9 kVA. The EV owners will be able to start/stop the charging as they need, set their desire schedules, or ultimately rely on a smart-charging algorithm that will balance the preferences of the two EV owners. Through simulation it will be possible to study a situation where the four places are occupied by EVs.

Western Europe Demo – Location 2

Location 2 in the Western Europe Demo is a semi-public parking lot in Lisbon. This parking lot already has 64 low-rated capacity chargers, 60 of which are operated by a third-party and the other four can be operated directly. This will be supplemented with two V2G 11kW chargers and a matrix charging pad, installed in the context of the AHEAD project.

For this demo, control algorithms will be developed to control the 64 low-rated chargers with several objectives in mind: 1) optimize the power distribution across the 64 chargers to avoid circuit and secondary substation overloading, 2) optimize the power distribution considering the presence (through simulation) of BESS and PV in the parking lot premises.

Related primary use case

<i>ID</i>	<i>Name</i>	<i>Description</i>
PUC2.1	Charging Optimization	Create an algorithm that dynamically allocates power between grid, BESS, and RES, optimizing charging speed, cost, and grid stability
PUC2.2	RES-BESS Coordination	This use case is focused on balancing real-time RES generation and BESS charge/discharge to minimize grid dependence.
PUC2.3	Scheduling vs modulation control algorithm for managing EV charging station	This use case compares pre-planned with real-time modulation. Assesses their impact on charging efficiency, grid stability, and user experience to determine the most effective strategy.

Related specialized use case

<i>ID</i>	<i>Name</i>
SUC2.1	Nordic Europe demo – Risø Campus/Danish countryside (slow/fast charging demo)
SUC2.2	Southern Europe demo – Milan and Kranj
SUC2.3	Western Europe demo – Lisbon

Key performance indicators (KPI)

Key performance indicators			
ID	Name	Description	Reference to mentioned use case objectives
KPI2.1	Charging Efficiency	Percentage of power utilization for charging	Objective 1,2
KPI2.2	Grid Dependency Reduction	Percentage of energy supplied from BESS-RES	Objective 2
KPI2.3	Uptime	Percentage of time that the charging station are operational	Objective 1,3
KPI2.4	Energy Cost Saving	Reduction in electricity cost with optimized scheduling	Objective 1
KPI2.5	Average charged energy	The average amount of energy delivered to EVs per charging session over a given period.	Objective 1,2
KPI2.6	Number of charging sessions per day/month	The total count of completed charging sessions at the station within a 24-hour or 30-day period.	Objective 1
KPI2.7	Energy produced by the RES	The total amount of electricity generated by RES within a specific period.	Objective 2
KPI2.8	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.	Objective 2
KPI2.9	Self-consumption	The proportion of RES that is consumed locally for EV charging instead of being exported to the grid.	Objective 2

Use case conditions

Use case conditions
Assumptions
The grid has limited power availability
Vehicles arrive randomly for charging
The charging station has BESS and RES integration
The EVSE has a maximum power deliverable
Prerequisites
The charging station must have a communication system for power control.
An algorithm must be implemented to manage charging priorities.
The charging site has multiple outlets.

Further information to the use case for classification/mapping

Classification information
Relation to other use cases
HLUC5 – Slow charging at workplaces is investigated for a similar (RES+BESS) scenarios
HLUC9 – Coordinated charging and user engagement are investigated
HLUC11 – Flexibility services are investigated
Level of depth
HLUC2 – Charging Stations with low-rated capacity:

- PUC2.1 – Charging optimization
- PUC2.2 – RES-BESS coordination
- PUC2.3 – Scheduling vs modulation control algorithm for managing EV charging station.
- SUC2.1 – Nordic Europe demo (Risø Campus/Danish countryside)
- SUC2.2 – Southern Europe demo (Milan and Kranj)
- SUC2.3 – Western Europe demo (Lisbon)

Prioritisation

High priority – The use case addresses both business and technical needs: optimization of power usage, reduction of grid dependency, and demonstration of flexibility potential. It directly supports political targets on RES integration and cost-effective EV infrastructure expansion.

Generic, regional or national relation

Generic

Nature of the use case

Technical/system/business use case

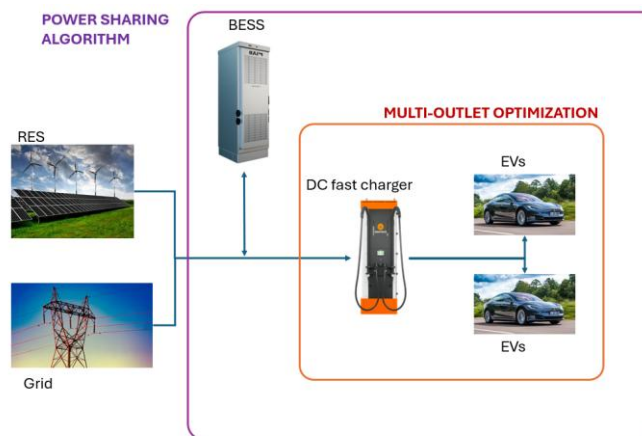
Further keywords for classification

EV charging stations, smart charging, RES integration, BESS coordination, demand response, power optimization, multi-outlet charging, scheduling algorithms, flexibility services, grid constraints.

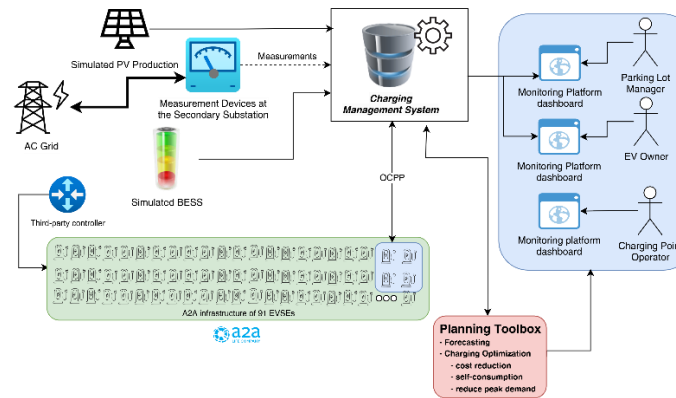
Diagram of use case

Diagram(s) of use case

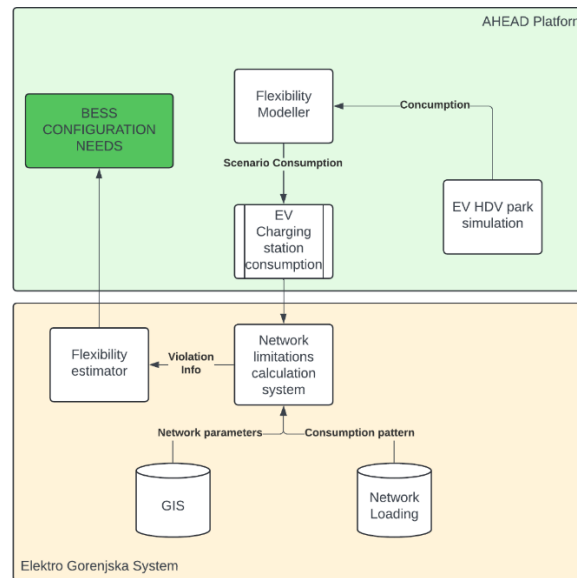
SUC2.1: Nordic Europe demo



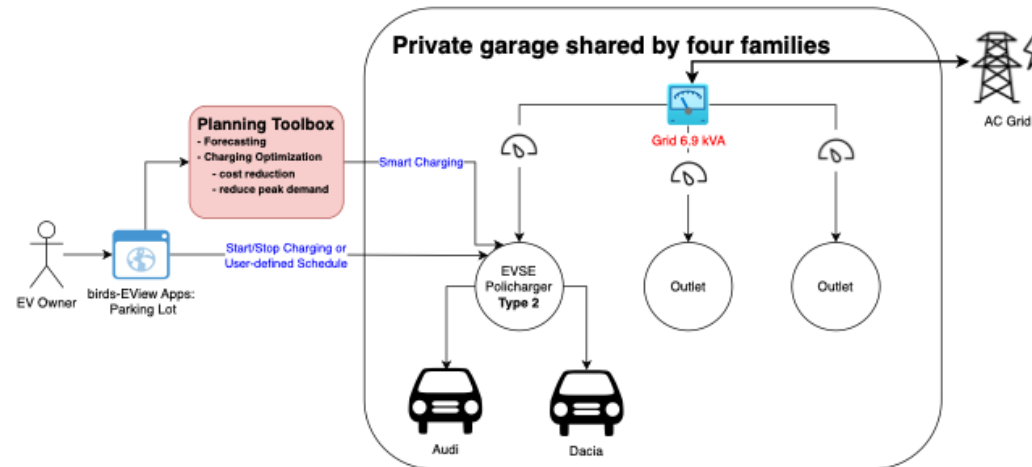
SUC2.2: Southern Europe demo (Milan)



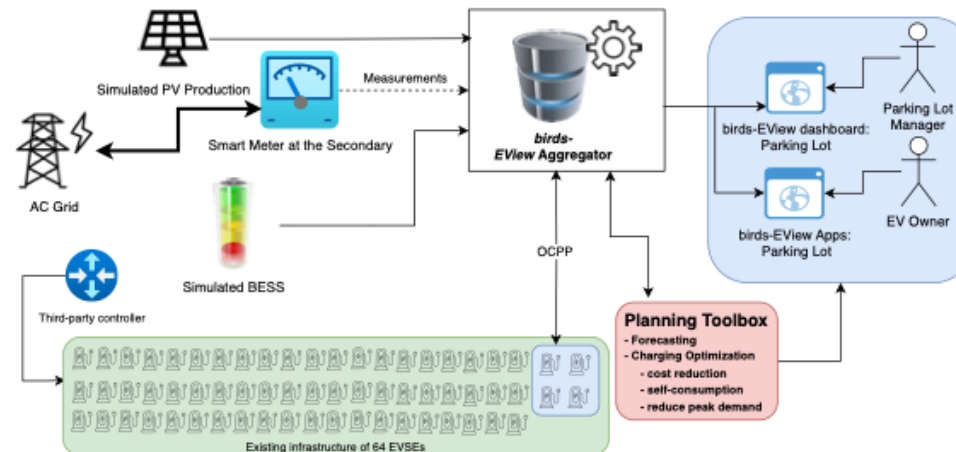
SUC2.2: Southern Europe demo (Kranj)



SUC2.3: Western Europe demo -Location 1



SUC2.3: Western Europe demo -Location 2



Technical details

Actors

Actors			
Grouping		Group description	
End -user		Human actors directly involved in EV charging.	
Actor name	Actor type	Actor description	Further information specific to this use case
EV Owner/User	Human Actor	Individual end-user charging their electric vehicle. Provides charging preferences and receives the service.	Triggers charging request and defines comfort constraints.

Actors			
Grouping		Group description	
System and service providers		Actors (business, logical, software, or hardware) that enable, manage, and optimize the operation of EV charging services.	
Actor name	Actor type	Actor description	Further information specific to this use case
Smart Charging Station (SCS)	System/Hardware Actor	Physical charging infrastructure delivering energy to EVs.	Communicates connection status and executes charging commands.
Parking Lot Energy Management System (EMS)	System/Software Actor	Centralized system coordinating energy flows among EVs, grid, BESS, and RES.	Collects information, dispatches charging, ensures grid constraints are respected.
Smart Scheduling Algorithm (SSA)	Logical Actor	Optimization component embedded in EMS that calculates and updates charging schedules.	Ensures efficient use of grid power, RES, and BESS.
DSO/Transmission system operator (TSO)	Business Actor	Grid operators that may issue flexibility requests to adapt charging demand.	Provide signals to EMS/SSA when grid balancing is needed.

Step-by-step analysis of use case

Overview of scenarios

Scenario conditions

No.	Scenario name	Scenario description	Primary actor	Triggering event	Pre-condition	Post-condition
1	Optimal Energy Management	EV arrives at the charging station and the EMS/SSA optimizes power allocation using grid, BESS, and RES data.	Parking Lot EMS/SSA	EV user requests charging	Charging station operational, EMS connected to grid/BESS/RES, user preferences available.	EV charged according to optimized schedule, ensuring grid stability, cost efficiency, and user comfort.

Steps-scenarios

Scenario							
Scenario name:		No. 1 – Optimal Energy Management					
Step No.	Event	Name of process/activity	Description of process/activity	Service	Information producer (actor)	Information receiver (actor)	Information exchanged (IDs)
1.1	EV arrival at the parking lot	EV Arrival Notification	The EV reaches the parking facility, where the driver parks in an available charging spot.	REPORT	EV Owner/User	Parking Lot EMS	IE-1.1
1.2	Connection detected	Register EV connection	The charging infrastructure establishes a link with the electric vehicle and sets it up for use.	CREATE	SCS	Parking Lot EMS	IE-1.2
1.3	Charging request submitted	Charging Request Submission	EV user provides charging preferences (e.g., state-of-charge (SOC), departure time).	REPORT	EV Owner/User	Parking Lot EMS	IE-1.3
1.4	Grid and local resources update	Context Data Acquisition	EMS collects available grid power, BESS SOC, RES forecast, and price signals as input for optimization.	REPORT	DSO/TSO (for grid & price), EMS sensors (for BESS/RES)	Parking Lot EMS/SSA	IE-1.4
1.5	Optimization requested	Charging Schedule Optimization	EMS/SSA computes an optimized charging schedule based on user preferences and context data.	CREATE	SSA	Parking Lot EMS	IE-1.5
1.6	Charging starts	Initiate charging	EMS, through SSA, instructs SCS to apply the optimized charging schedule.	EXECUTE	SSA	SCS	IE-1.6
1.7	Flexibility request received	Flexibility Adjustment	DSO/TSO may request EMS/SSA to reduce or shift charging for balancing. SSA adapts schedule accordingly.	CREATE	DSO/TSO	Parking Lot EMS/SSA	IE-1.7

1.8	Charging complete	End charging session	Charging session ends when EV reaches desired SOC or user-defined end time.	EXECUTE	SCS	EV Owner/User	IE-1.8
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Information exchanged

Information exchanged		
Information exchanged, ID	Name of information	Description of information exchanged
IE-1.1	EV Arrival Notification	Real-time notification that an EV has arrived at the charging facility.
IE-1.2	Connection Status	Confirmation that the EV is connected and ready for charging.
IE-1.3	Charging Request Submission	EV user preferences (SOC, departure time, charging priority).
IE-1.4	Context Data Package	Aggregated context data: available grid power, BESS SOC, RES production forecast, energy price.
IE-1.5	Optimized Charging Schedule	Optimized charging plan calculated by SSA for execution.
IE-1.6	Charging Start Command	Instruction from EMS/SSA to SCS to begin charging with defined schedule.
IE-1.7	Flexibility Request (from DSO/TSO)	Requests from the grid operator to reduce or shift consumption for grid balancing.
IE-1.6	Charging Session Feedback	Status updates from each charger: charging progress, delivered power, disconnection events, or errors.

Common terms and definitions

Common terms and definitions	
Term	Definition
BESS	Battery energy storage system
DSO	Distribution system operator
EMS	Energy management system
EV	Electric vehicle
EVSE	Electric vehicle supply equipment
HLUC	High-level use case
HV	High voltage
MV	Medium voltage
PUC	Primary use case
RES	Renewable energy source
SCS	Smart charging station
SOC	State-of-charge
SSA	Smart scheduling algorithm
SUC	Specialized use case
TSO	Transmission system operator
EVSE	Electric Vehicle Supply Equipment

II.III HLUC3 – Cyber-secure charging platform

Description of the use case

Name of the use case

Use case identification		
ID	Area/Domain(s)/Zone(s)	Name of use case
	Area: Energy System Domain: distribution system Zones: Operation, Station, Field	Cybersecure charging platform

Version management

Version management			
Version No.	Date	Name of author(s)	Changes
0.0	05.09.24	Marzio Barresi (POLIMI)	First template provided
0.1	21.02.25	Stefano Longari (POLIMI)	First draft of HLUC3
0.2	28.05.25	Stefano Longari (POLIMI)	Second draft of HLUC3
0.3	22.10.25	Marzio Barresi (POLIMI)	Final draft version of HLUC3

Scope and objectives of use case

Scope and objectives of use case	
Scope	The High-Level Use Case (HLUC) focuses on the identification and evaluation of cybersecurity threats and vulnerabilities that affect electric vehicle (EV) charging infrastructures. It considers both existing deployments using Open Charge Point Protocol (OCPP) 1.6 and newer implementations adopting OCPP 2.x Plug&Charge. The analysis also evaluates the effectiveness of cybersecurity mitigations when applied to realistic threat scenarios. Three primary use cases (PUCs) that will be developed: • PUC3.1 – Threat Identification and Analysis • PUC3.2 – Evaluation of Cybersecurity Mitigations • PUC3.3 - Comparative Assessment of OCPP 1.6 vs OCPP 2.x Plug&Charge Three specialized use cases (SUCs) will be developed according to the demos. • SUC3.1 – Nordic Europe demo • SUC3.2 – Southern Europe demo • SUC3.3 – Western Europe demo
Objective(s)	1. Cybersecurity Analysis: conduct an evaluation of existing threats and vulnerabilities affecting standard charging infrastructure, specifically communication protocols and charging station endpoints.

	2. Mitigation Capabilities: analyse the effectiveness of selected mitigation strategies in preventing, detecting, or limiting the impact of cyberattacks. 3. OCPP 2.x Plug&Charge: assess the potential benefits and drawbacks of adopting OCPP 2.x Plug&Charge protocols, including an analysis of added security features, new threat vectors, and implementation challenges.
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[Narrative of use case](#)

<i>Narrative of use case</i>	
Short description	
This use case investigates the cybersecurity posture of EV charging infrastructure by simulating cyberattacks targeting two major elements of the domain—namely, the OCPP and the charging stations. It evaluates the impact of these attacks and analyses countermeasures, which are expected to be introduced with more advanced versions of the OCPP protocol (e.g., OCPP 2.x Plug&Charge).	
Complete description	
Cyberattacks targeting EV charging infrastructure can target user privacy, disrupt services, and pose safety risks. This use case addresses these challenges by simulating realistic threat scenarios and assessing their consequences on the charging ecosystem. The analysis centres on two major components of the charging infrastructure: the OCPP protocol and the charging station hardware. 1. Threat Identification: Simulated attacks are executed to uncover vulnerabilities and impacts in these elements, which are unique to the EV charging domain. 2. Mitigation Evaluation: The use case assesses if and how newer protocol versions (e.g., OCPP 2.x) and endpoint-level protections are targeting the challenge to strengthen the system's resilience. A comparative analysis of OCPP versions investigates the potential improvements in communication security, authentication, and protocol robustness. Charging station endpoints are also scrutinized to reveal potential weaknesses, with and without mitigation strategies in place. These evaluations enable the formulation of actionable recommendations for securing current and future deployments.	

[Related primary use case](#)

<i>ID</i>	<i>Name</i>	<i>Description</i>
PUC 3.1	Threat Identification and Analysis	This use case focuses on the identification of vulnerabilities and threats affecting EV charging infrastructure. It considers both legacy OCPP 1.6 deployments and newer OCPP 2.x implementations, including Plug&Charge functionalities. Threat modelling is performed by simulating cyberattacks against network communications and charging station endpoints. The objective is to classify the vulnerabilities, understand the impact on system confidentiality, integrity, and availability, and provide a baseline threat catalogue for the charging ecosystem.
PUC3.2	Evaluation of Cybersecurity Mitigations	This use case investigates the effectiveness of different cybersecurity countermeasures, including authentication, encryption, intrusion detection, and endpoint hardening. It compares their performance in preventing, detecting, or limiting the impact of simulated attacks on OCPP-based communication and charging stations. The analysis covers how these mitigations operate under different threat scenarios and provides insights into their applicability for real-world deployments.

PUC 3.3	Comparative Assessment of OCPP 1.6 vs OCPP 2.x Plug&Charge	This use case provides a structured comparison between OCPP 1.6 and OCPP 2.x Plug&Charge protocols from a cybersecurity perspective. It examines how the adoption of OCPP 2.x improves security features such as authentication, encryption, and trust establishment, while also considering new vulnerabilities introduced by the added complexity of Plug&Charge. The goal is to highlight both the advantages and limitations of migrating to newer standards and to inform stakeholders about the security trade-offs of implementation choices.
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[Related specialized use case](#)

ID	Name
SUC3.1	Nordic Europe demo
SUC3.2	Southern Europe demo
SUC3.3	Western Europe Demo

[Key performance indicators \(KPI\)](#)

Key performance indicators			
ID	Name	Description	Reference to mentioned use case objectives
KPI3.1	Effectiveness of Mitigations	Number and severity of attack scenarios that are successfully mitigated by implemented security measures, including those tested on OCPP 2.x..	Objective 2, 3
KPI3.2	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.	Objective 1, 3
KPI3.3	Endpoint Vulnerability Insights	Number and types of exploitable weaknesses identified on charging stations.	Objective 1, 2

[Use case conditions](#)

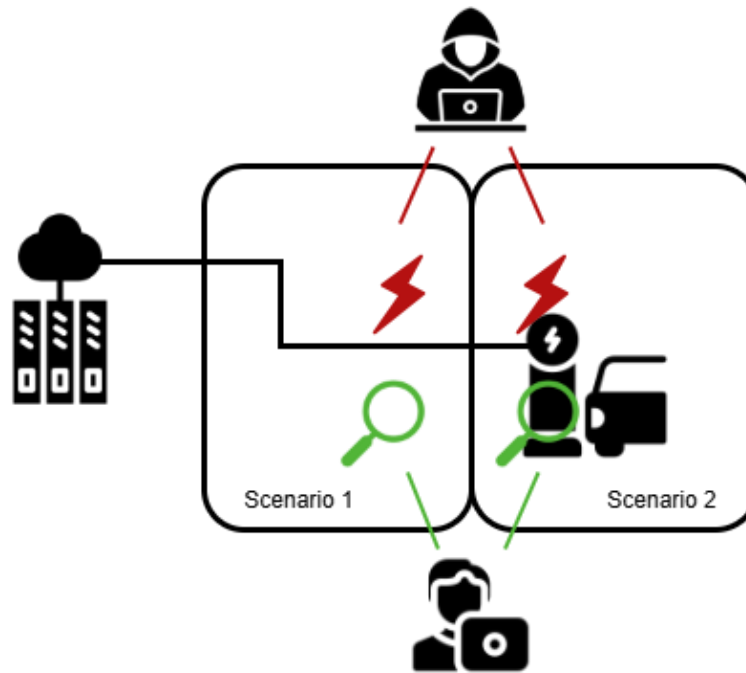
Use case conditions
Assumptions
The attacker has logical access to the communication network connecting charging stations and the backend management systems (e.g., charge point management system (CPMS)). This may simulate either an internal threat actor (e.g., compromised node) or an external actor that has breached perimeter defences.
Both legacy (OCPP 1.6) and newer (OCPP 2.x) protocol versions are available for evaluation, along with the necessary software or firmware interfaces to configure, monitor, and test them.
The charging stations used for analysis are considered representative of those currently deployed in the field.
Prerequisites
Implementations of OCPP 1.6 and OCPP 2.x (e.g., 2.0.1 or newer) are installed and configured in the testbed, with appropriate interfaces to simulate message exchanges and perform protocol-specific testing.
Physical and logical access to the charging station is available for the purpose of executing security assessments and simulated attack scenarios.

[Further information to the use case for classification/mapping](#)

Classification information
Relation to other use cases
This use case is cross-cutting and supports several other use cases by ensuring secure and resilient communication and control in EV charging. It is related to HLUC1, HLUC2, HLUC5, HLUC7, HLUC8, HLUC9, HLUC10, HLUC11, HLUC12.
Level of depth
HLUC3 – Cybersecure Charging Platform • PUC3.1 – Threat Identification and Analysis • PUC3.2 – Evaluation of Cybersecurity Mitigations • PUC3.3 – Comparative Assessment of OCPP 1.6 vs OCPP 2.x Plug&Charge. ▪ SUC3.1 – Nordic Europe demo ▪ SUC3.2 – Southern Europe demo ▪ SUC3.3 – Western Europe demo
Prioritisation
Medium priority for the AHEAD project and the overall e-charging infrastructure stakeholders, since implementation of vulnerable standards and hardware components may not be easily patchable at runtime, however regulations and previous analyses of the OCPP standard already provide a basic level of security.
Generic, regional or national relation
Generic
Nature of the use case
Technical/Test use case
Further keywords for classification
Cybersecurity, vulnerability analysis, countermeasure implementation

Diagram of use case

Diagram(s) of use case



Technical details

Actors

Actors			
Grouping		Group description	
Cybersecurity stakeholder		This group includes human actors directly responsible for developing, executing, and evaluating cybersecurity tests and countermeasures in the EV charging ecosystem.	
Actor name	Actor type	Actor description	Further information specific to this use case
Security expert	Human	Responsible for developing security measures.	Produces expert reports and recommendations based on simulated attacks.
Attacker	Human	Simulated malicious actor executing attacks and attempting to exploit vulnerabilities in OCPP communication and charging stations.	Represents an ethical hacker in controlled testbed scenarios.

Actors			
Grouping		Group description	
Charging infrastructure and backend systems		This group includes all systems, devices, and platforms involved in EV charging communication, operation, and management that may be targeted or protected in the cybersecurity analysis.	
Actor name	Actor type	Actor description	Further information specific to this use case
Charging station	Device	Physical charging infrastructure providing EV charging services and acting as a potential attack target.	Includes vehicle-to-grid (V2G)-enabled functionalities and station-level endpoints.
CPMS/EMS	System	Backend management systems	May be targeted by cyberattacks or provide monitoring logs for analysis.
Network (OCPP infrastructure)	System	Communication layer connecting charging stations and backend (CPMS), supporting OCPP.	Evaluated under attack to compare vulnerabilities and mitigations.

Actors			
Grouping		Group description	
Attack simulation tools		This group includes the systems or devices used to execute cyberattacks or inject malicious traffic into the charging ecosystem for testing purposes.	
Actor name	Actor type	Actor description	Further information specific to this use case
Attacker's station	Device	A dedicated device or emulated charging station controlled by the attacker to launch attacks.	Used to inject test traffic and emulate malicious behaviour against the charging infrastructure.
Victim	Device	Entity under attack (charging station or backend system).	Provides logs and feedback to evaluate the impact of attacks.

Step-by-step analysis of use case

[Overview of scenarios](#)

Scenario conditions						
No.	Scenario name	Scenario description	Primary actor	Triggering event	Pre-condition	Post-condition
1	OCPP 2.x as a potential mitigation to attacks developed on OCPP 1.6	The first scenario has the goal to understand the impact of using OCPP 2.0.1, its authentication capabilities, and evaluate the impact of such security measures as potential mitigation of the known attacks available for OCPP 1.6	Attacker's station	Attacker connects to OCPP network	Network (OCPP 1.6)	Network (OCPP 2.x) with expected upgrades (by definition by 2.x) for protection from attacks

2	Threats against the charging station	The second scenario has the goal to demonstrate the impact of known threats against a V2G-enabled charging station and test its cybersecurity.	Attacker	Attacker gains access to charging station	Charging station operational and connected to CPMS	Security expert receives report on vulnerabilities and impacts.
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Steps-scenarios

Scenario							
Scenario name:		No. 1 - OCPP 2.x as a potential mitigation to attacks developed on OCPP 1.6					
Step No.	Event	Name of process/activity	Description of process/activity	Service	Information producer (actor)	Information receiver (actor)	Information exchanged (IDs)
1.1	Connection of attacker to the OCPP network	Attacker Access	The attacker connects the attacker's station to the OCPP enabled network. The attacker analyses the network to recover necessary knowledge to execute the attack.	GET	Attacker's station	Network (OCPP infrastructure)	IE-1.1
1.2	Execution of attacks against OCPP 1.6 network	Attacks against 1.6	The attacker implements the attacks (produced in the threat modelling task of WP5) on the network, against the relevant victims	CREATE	Attacker's station	Victim (Charging Station/CPMS)	IE-1.1; IE-1.2
1.3	Report on the impact of attacks on the OCPP 1.6 network	Reporting of 1.6	The security expert collects the logs of the events and analyses the impact of attacks on the network and on the victim devices	GET	Victim (Charging Station/CPMS)	Security Expert	IE-1.3
1.4	Execution of attacks against OCPP 2.0.1 network	Attacks against 2.0.1	The attacker implements the attacks (produced in the threat modelling task of WP5) on the network, against the relevant victims	CREATE	Attacker's station	Victim (Charging Station/CPMS)	IE-1.1; IE-1.2
1.5	Report on the impact of attacks on the OCPP 2.0.1 network	Reporting of 2.0.1	The security expert collects the logs of the events and analyses the impact of attacks on the network and on the victim devices	GET	Victim (Charging Station/CPMS)	Security Expert	IE-1.3

Scenario	
Scenario name:	No. 2 - Threats against the charging station

Step No.	Event	Name of process/activity	Description of process/activity	Service	Information producer (actor)	Information receiver (actor)	Information exchanged (IDs)
2.1	Analysis	Security analysis of the charging station	The attacker analyses the documentation and the charging station itself and reverse engineers its functioning to identify potential vulnerabilities and weaknesses	GET	Charging station	Attacker	IE-2.1
2.2	Exploitation	Exploitation of found vulnerabilities	The attacker exploits detected vulnerabilities to implement attacks against the charging station	EXECUTE	Attacker	Charging station	IE-1.1; IE-1.2
2.3	Reporting	Report on the impact of attacks	The effects of the attacks are collected in a report to describe the potential capabilities of an attacker	GET	Charging station	Security expert	IE-1.3

Information exchanged

Information exchanged		
Information exchanged, ID	Name of information	Description of information exchanged
IE-1.1	Attack sequence	Sequence of steps that the attacker executes to obtain its goals
IE-1.2	Victim's feedback	Behaviour of the victim during or after the attack
IE-1.3	Expert's report	Report on the impact of the attack produced a posteriori
IE-2.1	Threats list	Report on the potential executable threats, found vulnerabilities, and reverse engineering of relevant functions

Common terms and definitions

Common terms and definitions	
Term	Definition
CPMS (Charge Point Management System)	The backend system responsible for managing multiple charging stations.
EV	Electric vehicle
HLUC	High-level use case
OCPP (Open Charge Point Protocol)	A communication protocol used between EV charging stations and central management systems. Versions 1.6 and 2.x are considered in this use case.
Plug&Charge	A mechanism enabling seamless and automated user authentication and billing between EVs and charging stations.
PUC	Primary use case
SUC	Specialized use case
V2G (Vehicle-to-Grid)	Technology enabling bidirectional energy exchange between EVs and the power grid.

II.IV HLUC4 – Novel charging technologies

Description of the use case

Name of the use case

Use case identification		
ID	Area/Domain(s)/Zone(s)	Name of use case
HLUC4	Area: energy system Domain: distribution system Zones: operation, station, field	Novel charging technologies

Version management

Version management			
Version No.	Date	Name of author(s)	Changes
0.0	05.09.24	Marzio Barresi (POLIMI)	First template provided
0.1	02.06.25	Lucas Pereira (IST-ID), Gustavo Miranda (IST-ID), Cindy Guzman (INESC-ID)	First draft of HLUC4
0.2	22.10.25	Marzio Barresi (POLIMI)	Final draft version of HLUC4

Scope and objectives of use case

Scope and objectives of use case	
Scope	The High-Level Use Case (HLUC) focuses on the demonstration of novel charging technologies, which will be achieved in a mix of real-world and simulated environment considering urban, rural, and maritime sector. Ultimately, this use case intends to form the technological basis for the development of some of the remaining AHEAD use cases. Three Primary Use Cases (PUCs) will be derived from this HLUC. 1) <u>PUC4.1 – Matrix-based charging technologies.</u> Scope: <i>Test the technical feasibility of matrix-based electric vehicle (EV) charging technology. The focus will be on the technical installation and demonstration of the AC bidirectional charging.</i> 2) <u>PUC4.2 – Vessel charging technologies.</u> Scope: <i>Test the technical feasibility of charging electric and hybrid vessels using AC charging technology. The focus is on small-scale vessels, e.g., catamarans.</i> 3) <u>PUC4.3 – Heavy-Duty/Buses Charging.</u> Scope: <i>Assess the technical feasibility of heavy-duty (HDV) and buses charging. The heavy-duty charging will be tested through simulation, whereas the buses charging will be tested in real-life conditions.</i> Three Specialized Use Cases (SUCs) will be derived according to demo site: ▪ SUC4.1 – Western Europe demo – Lisbon ▪ SUC4.2 – Western Europe demo – Funchal ▪ SUC4.3 – Southern Europe demo – Italy (Milan) and Slovenia (Kranj)

Objective(s)	1) <u>PUC4.1 – Matrix-based charging technologies.</u> Objective: Deploy the charging infrastructure to conduct exploratory tests on wireless charging in a private parking lot; participate in the retrofitting on an EV to support matrix-based charging; design and evaluate a use case that considers the possibility of using matrix-based charging in the daily operations at the parking lot. 2) <u>PUC4.2 – Vessel charging technologies.</u> Objective: Identify the charging infrastructure requirements for fleets of electric or hybrid vessels; Retrofit an existing AC charging infrastructure to support monitoring and smart charging of small vessels; Test and evaluate the performance of the developed system with vessels operating in real-world conditions. 3) <u>PUC4.3 – Heavy-Duty/Buses Charging.</u> Objective: Install a Kempower vehicle-to-grid (V2G) charging station at Location 1 (Italy) to conduct real-world tests on the flexibility services that electric buses can provide to the distribution system operator (DSO) grid. At Location 2 (Slovenia), simulate charging strategies and the flexibility potential of HDVs and public transport fleets in a simulation environment.
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Narrative of use case

Narrative of use case
Short description The use case focuses on testing novel charging technologies by studying and exploring the feasibility of charging “standard” EVs using inductive technology, charging small scale vessels using AC charging, charging of HDV, including buses and trucks. Altogether, the objective of this use case is to shed some light in these areas that are currently starting to be explored. Furthermore, this use case will also lay the foundations for other use cases in the project. Namely, HLUC5 (smart charging in workplaces), HLUC6 (smart charging at depots), and HLUC8 (charging in port areas).
Complete description This use case is dedicated to the analysis of innovative charging technologies across various contexts, including private parking lots, maritime environments, rural and urban areas. The validation of novel charging technologies in private parking lots will be achieved through the deployment of a complete charging infrastructure, enabling an in-depth evaluation of wireless charging functionality. This process will include the retrofitting of an EV to ensure compatibility with the wireless charging system. The exploration of this technology's functionality will be structured around a matrix-based smart charging framework to optimize the daily operations in the parking lot. This framework encompasses the installation and monitoring of EV energy consumption, measurement and control of charging station performance, implementation of control actions for charging stations, development of a management dashboard for parking lot operators, and the provision of a graphical interface for EV owners. The anticipated results include the optimization of daily operations through the reduction of downtime and inefficiencies associated with manual interventions in charging processes. Additionally, the system is expected to foster greater interest in the adoption of wireless charging technologies among parking lot operators and EV owners. Heavy-duty and bus charging will be assessed through both real-world and simulated environments. In Italy, a Kempower V2G station will enable tests on electric bus fleets and their potential to support the DSO grid. In Slovenia, simulations will explore the flexibility contribution of HDVs and public transport fleets. The outcomes will provide insights into scalability, optimal fleet charging strategies, and the grid services that such fleets can offer. The maritime oriented technology is focused on to identify the main charging infrastructure requirements for fleets of electric or hybrid vessels. An existing AC charging infrastructure to support monitoring and control actions in small vessels will be implemented to validate smart charging operations in a real-world scenario. The investigation of this technology's functionality will be structured around a smart charging framework designed to optimize the daily operations of multiple charging points within a port, including the integration of a smart charging station. This framework includes the installation and real-time monitoring of energy consumption by electric vessels, the measurement and control of charging station performance, and the implementation of advanced control actions to enhance operational efficiency. Additionally, the framework involves the development of a comprehensive management dashboard tailored for both the DSO and the port authority, as well as a graphical interface designed to meet the operational needs of vessel companies. The anticipated outcomes of this system include validating the framework's capability to provide precise and continuous monitoring of electric vessel energy consumption and charging station performance, ensuring the effective implementation of control strategies to facilitate seamless operations and optimal load balancing, and optimizing the management of charging resources to meet vessel energy demands while maintaining overall system stability. Additionally, the

system aims to enhance decision-making processes for the DSO and port authority by integrating a centralized management dashboard, enabling data-driven operational strategies.

[Related primary use case](#)

ID	Name	Description
PUC4.1	Matrix-based charging technologies	Understanding the installation requirements for matrix-based charging, performing the installation and retrofitting an EV to enable testing the charging technology. It is important to stress that the charging will be bi-directional in AC. A key characteristic of the use case is the simulation of dynamic charging and parking patterns, including repeated arrivals and departures of the same EV during the day, in order to evaluate matrix-based charging technologies under realistic operating conditions and different charging-management strategies, including uncoordinated charging and V1G operation.
PUC4.2	Vessel charging technologies	Understanding how electric and hybrid vessels dedicated to maritime-touristic activities (e.g., catamarans) can be charged. This case will focus on AC charging, and for that effect the team will retrofit an existing electricity supply point to also support the smart charging of such vessels. A key characteristic of this retrofitting is that it will support the sending of ON and OFF commands to the charger using open charge point protocol (OCPP).
PUC4.3	Heavy-Duty/Buses Charging	Understanding how electric buses and heavy-duty vehicles can contribute to flexibility services through smart and bidirectional charging. In Location 1 (Italy), a Kempower V2G charging station will be installed and connected to an electric bus to test real-world capabilities of energy withdrawal reduction and energy injection into the DSO grid. In Location 2 (Slovenia), simulations will be conducted to evaluate charging strategies and flexibility potentials for HDVs and public transport fleets.

[Related specialized use case](#)

ID	Name	Description
SUC4.1	Western Europe demo – Lisbon	The charging system (matrix-based charger) will be installed in the EDP parking lot in Lisbon and integrated into the existing platform of controlling EVSEs. Ideally the charger will also be integrated into the <i>birdsEView</i> platform. In the end, it should be able to test bi-directional charging.
SUC4.2	Western Europe demo – Funchal	The vessel charging system will be integrated in the <i>birdsEView</i> platform, developed for the Western European demos, and will include a mobile Application to visualize and change the status of the chargers. In the end, it should be possible to test the developed system using at least one of the vessels in the Port of Funchal.
SUC4.3	Southern Europe demo	For Location 1 (Italy), the bus charging system will be installed at the A2A test site, located in the parking lot/charging hub within the primary substation (high voltage (HV)/medium voltage (MV)) in Milan. The system will include a Kempower charger with 80 kW continuous power and up to 100 kW peak power. An advanced interface will be exploited to control the bidirectional charging process, enabling coordination between the charger, the bus battery, and the electrical grid. For Location 2 (Slovenia), the charging park will be simulated based on the simulation tool that will be developed in WP3. The idea is to analyse what kind of flexibility capacity the HDV/transport fleets/cars charging park will have and would offer to the DSO network via flexibility services. In real time and based on the active power consumption at the primary transformer station, the flexibility of EV charging will be simulated to emulate the provision of flexibility services at the demo location.

[Key performance indicators \(KPI\)](#)

Key performance indicators

ID	Name	Description	Reference to mentioned use case objectives
SUC4.1			
KPI4.1	Retrofitted EVSEs	Number of EVs retrofitted to support wireless charging technology. At least one EV should be successfully retrofitted and tested.	Objective 1
SUC4.2			
KPI4.2	Retrofitted Charging Points	Number of charging points retrofitted for the UC. At least one charging point should be developed and deployed.	Objective 2
KPI4.3	Tests with real vessels	Number of real vessels using the charging system. At least one real vessel should be able to charge using the developed solution.	Objective 2
SUC4.3			
KPI4.4	Installed V2G Charging Infrastructure	Number of V2G-capable charging points successfully installed and integrated at the test site. At least one Kempower charger should be operational and ready for testing.	Objective 3
KPI4.5	Bidirectional Charging Tests Performed	Successful commissioning and activation of the V2G charging station, including its integration with the control systems for energy flow management.	Objective 3
KPI4.6	Test the needed flexibility on the specific location	Identification of the needed flexibility need due to EV charging park.	Objective 3

Use case conditions

Use case conditions	
Assumptions	
SUC .1	
-	There is courier service that operated from the parking lot using an EV.
SUC4.2	
-	The vessels in the maritime-touristic activities will charge in AC using IEC 60309 connectors.
SUC4.3	
-	The electric buses participating in the test are compatible with the V2G communication protocols and technical requirements.
-	The DSO allows energy injection into the grid at the test site.
-	The simulation of the park and flexibility service simulation will be accurate.
-	The real-time data will be available from the primary transformer station.
Prerequisites	
SUC4.1	
-	An EV retrofitted to support matrix-based charging is available on the premises.
SUC4.2	
-	An electric connection is available in the proximity of the vessel docking areas.
-	A hybrid or fully electric vessel is available in the marina where the developed connector will be deployed.
SUC4.3	
-	A Kempower V2G charger is installed and physically connected at the Milan test site.
-	An electric bus is available and configured to support bidirectional charging.
-	The interface for managing the charger, battery, and grid is deployed and functional.

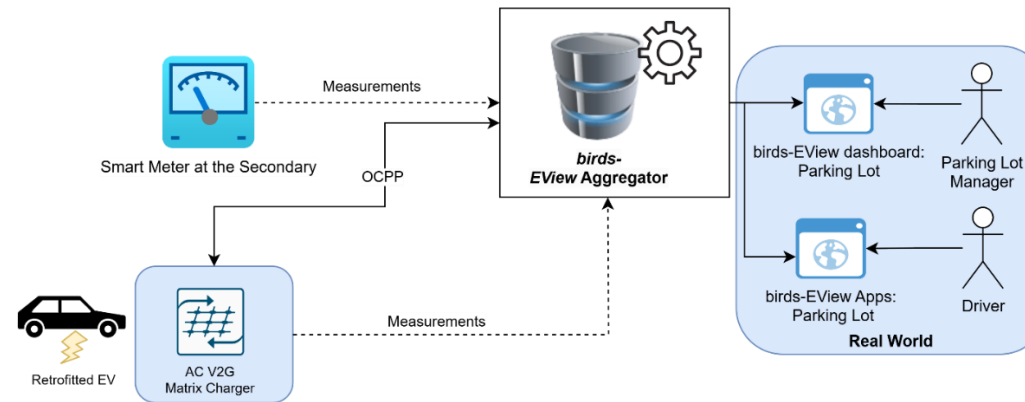
- The real-time data is present on the primary transformer station.
- The flexibility modelling is in the final stages.

[Further information to the use case for classification/mapping](#)

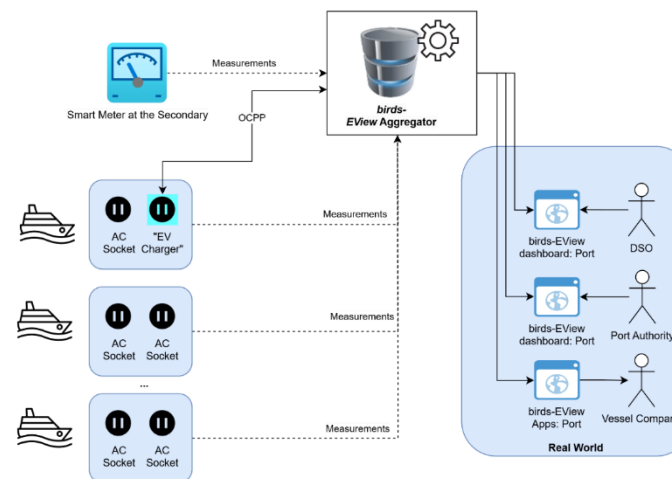
Classification information
Relation to other use cases
HLUC4 is directly related to HLUC1, HLUC5, HLUC6, HLUC8.
Level of depth
HLUC4 – Novel charging technologies • PUC4.1 – Technical feasibility and value proposition of wireless charging technologies • PUC4.2 – Technical feasibility and value proposition of vessels charging • PUC4.3 – Technical feasibility, challenges and opportunities provided by heavy-duty/bus charging. ▪ SUC4.1 – Western Europe demo - Lisbon ▪ SUC4.2 – Western Europe demo - Funchal ▪ SUC4.3 – Southern Europe demo
Prioritisation
High priority for the AHEAD project due to the relevance of these topics in the call for proposals. SUC4.1 and SUC4.2 have both technical and business relevance, since it is not clear yet how these technologies can be deployed in the real-world. But even more importantly, the business models are still very unclear. This is especially true for the SUC4.2 where maritime-tourism activities are still relying mainly on diesel engines and using wind for sailing. SUC4.3 has both technical and business relevance due to the strategic importance of electrifying heavy-duty transport and public mobility, aligning with EU goals for decarbonization. It focuses on testing V2G integration for buses in real-world conditions. While technology is still emerging, validating operational models and demonstrating flexibility services are essential to support future deployment and investment decisions. The technology and flexibility offerings from the HDV will be tested in a simulated environment.
Generic, regional or national relation
SUC4.2 and SUC4.3 may be impacted by the national/regional regulations. In the case of SUC4.2, there is yet no regulation regarding the electrification of this industry, but if it occurs during the project timeframe it can have some relevant impacts. SUC4.3 involves two different countries, which may have some very specific rules to address to.
Nature of the use case
These are mostly technical use cases that aim to assess how the technology can support different value propositions. The objective is not to create business models for the value propositions.
Further keywords for classification
Wireless EV charging infrastructure, AC vessel charging infrastructure, HDV charging infrastructure, value propositions, grid stability, AI-driven planning

Diagram of use case

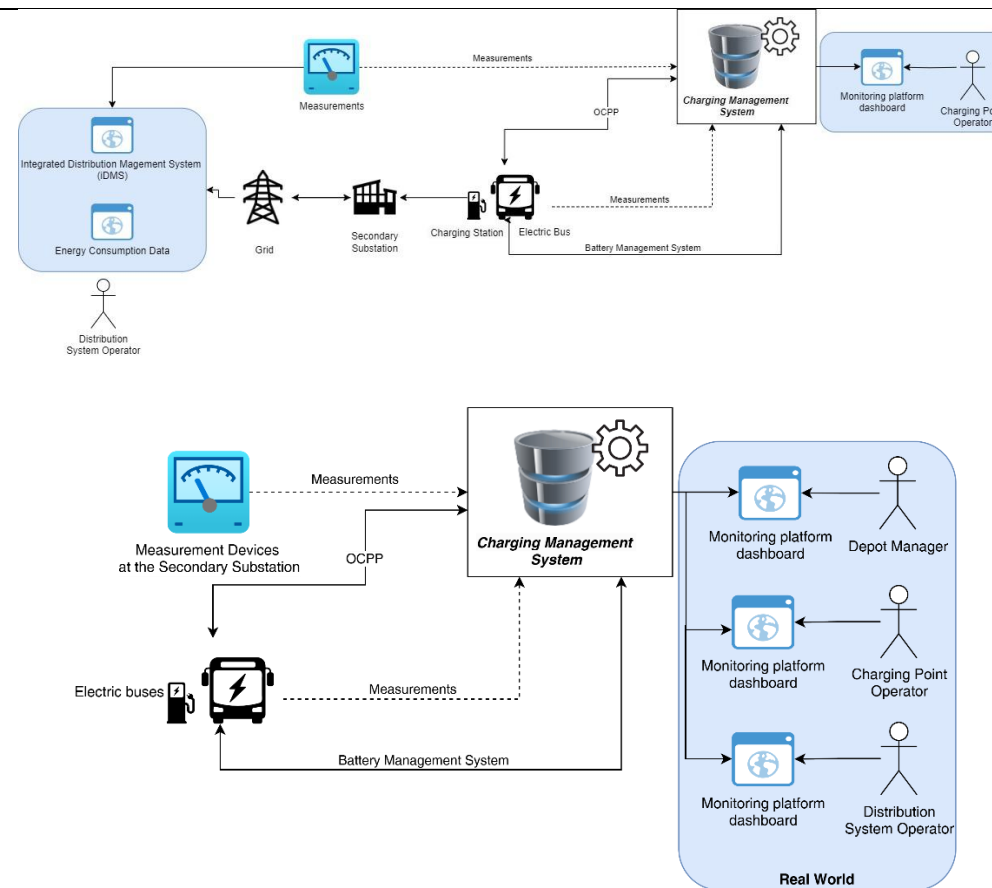
Diagram(s) of use case
SUC4.1: Western Europe demo – Lisbon



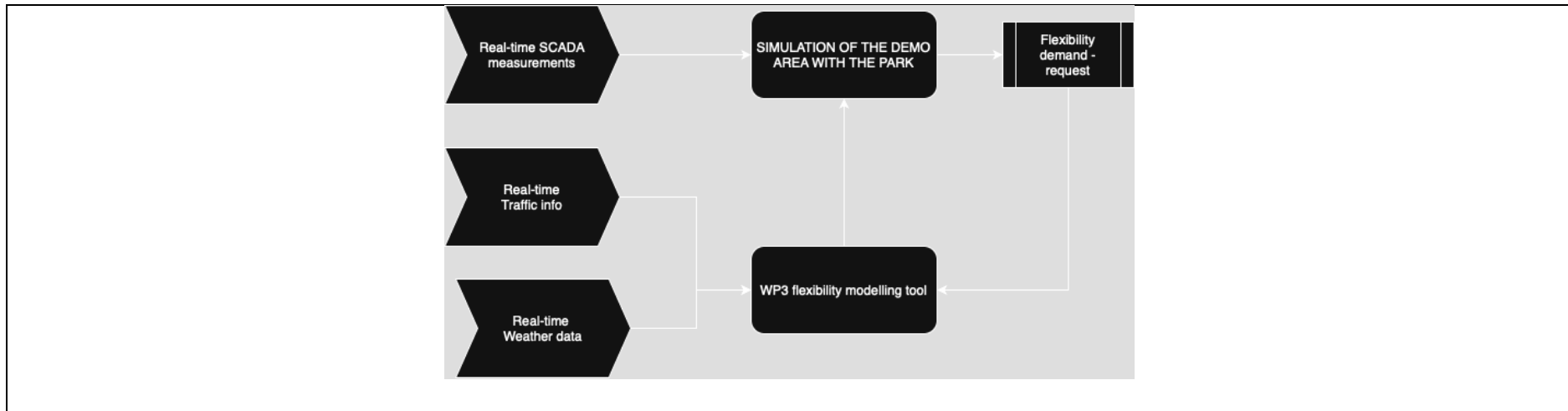
SUC4.1: Western Europe demo – Funchal



SUC4.3 – Southern Europe demo (Milan)



SUC4.3 – Southern Europe demo (Kranj)



Technical details

Actors

Actors			
Grouping		Group description	
Matrix-based Charging		This group includes human and non-human actors for the use case related to wireless charging (PUC4.1 – SUC4.1)	
Actor name	Actor type	Actor description	Further information specific to this use case
EV Owner	Human Actor	The individual or entity that owns and operates the EV retrofitted for wireless charging.	Provides feedback on user experience and charging efficiency.
Charging Infrastructure Provider	System Actor	The company responsible for supplying and maintaining the wireless charging infrastructure.	Ensures the technology functions as expected and integrates with existing charging networks.
Research Team	Human Actor	The team conducting the feasibility study on wireless charging.	Responsible for evaluating the test results and proposing future developments.
DSO	Human Actor	Responsible for monitoring and managing the impact of wireless charging on the electrical grid.	Assesses grid stability and adjusts power distribution as needed.
Courier	Human Actor	Representative from the company that owns the parking lot where testing occurs.	May participate in interviews to provide insights into practical implementation challenges and opportunities.
Monitoring Platform	System Actor	The monitoring platform is responsible for tracking and displaying real-time charging status updates, energy consumption, and session progress. It also interacts with charging stations, authoring the charging sessions and	Used to update charging progress in real-time and ensure proper data recording for further analysis.

Actors			
Grouping		Group description	
Vessel Charging		This group includes human and non-human actors for the use case related to vessel charging (PUC4.2 – SUC4.2)	
Actor name	Actor type	Actor description	Further information specific to this use case
Port Authority	Human Actor	This is the company that manages the Port. They provide and oversee the infrastructure – including the electrical installation.	The port authority provides information about the electrical installation.
Vessel Operator	Human Actor	The individual responsible for controlling the vessel during its operation, including choosing and managing its charging schedule.	The vessel operator ensures the vessel is charged before and after the trip, knowing that the charging will be aligning with the OCPP commands.
Vessel Company	Human Actor	These are the companies that operate the vessels.	From the companies, we can have access to their scheduled trips and details of their vessels. Having a trip schedule allows the planner to have an idea of when the vessel will leave the port. This is useful to schedule resources for vessel charging.
DSO	Human Actor	DSO is responsible for monitoring and controlling the electrical grid infrastructure. It interacts with the system to assess the impact of proposed charging stations on the grid and optimize resource allocation	Ensures that the deployment of charging stations aligns with grid capacity and overall grid optimization goals.
Electric/Hybrid Vessel	System Actor	These are the vessels that are operated by the vessel companies. They will be connected to the charger before and after the trips. Depending on being hybrid or fully electric the charging needs will be different.	For this particular use case the vessel will be assumed to charge in AC using IEC 60309 (commonly called “CEE” plugs).
Charger	System Actor	This is the vessel charger that implements the OCPP protocol and enables smart-charging via ON-OFF commands.	The charger will implement the OCPP protocol 2.0.1 or 2.1.
Monitoring Infrastructure	System Actor	Monitoring infrastructure to be deployed at the port area. This is useful to give an idea of the total electric demand of the port.	This is optional.
BirdsEView Platform	System Actor	This is the platform where the measurements are centralized and where some algorithms are executed.	
BirdsEView Dashboard: Port	System Actor	This is a dashboard that will be used to provide feedback to the port authority and to the DSO.	The main difference between the DSO and PA version is that the former will contain only aggregated measurements.
BirdsEView Apps: Port	System Actor	This is an app/dashboard that will be provided to the vessel operators.	This will be tested with at least one operator.

Actors			
Grouping		Group description	
Heavy-duty / Bus charging		This group includes human and non-human actors for the use case related to heavy-duty and bus charging (PUC4.3 – SUC4.3)	
Actor name	Actor type	Actor description	Further information specific to this use case
Driver	Human Actor	The person responsible for driving the electric bus and initiating the charging session at the depot.	Plugs the bus into the V2G charging station upon arrival at the depot.

Depot Manager	Human Actor	Oversees the operation of the bus depot and ensures buses are charged and ready for deployment.	Uses platform feedback to manage availability and schedule of buses.
Charging Management System	System Actor	Manages and schedules the charging and discharging processes based on grid signals and depot needs.	Coordinates with DSO and interfaces with Battery Management System and Monitoring Platform.
Battery Management System	System Actor	Monitors the battery (state of charge) SOC and manages technical communication with the charging system.	Sends information about battery status and controls charging/discharging operations.
Charge Point Operator (CPO)	Business Actor	Responsible for the operation, maintenance, and commercial management of charging stations.	Coordinates with the Charging Management System and DSO for flexibility provision.
DSO	Human Actor	Ensures the charging activities are aligned with grid constraints and may request energy flexibility.	Coordinates with the Charging Management System for V2G operations to support grid stability.
Monitoring Platform	System Actor	Collects and visualizes real-time data about charging sessions, energy usage, and system status.	Provides data feedback to depot operators and DSO.

Step-by-step analysis of use case

Overview of scenarios

Scenario conditions						
No.	Scenario name	Scenario description	Primary actor	Triggering event	Pre-condition	Post-condition
1	Matrix-Based Charging	Once an EV retrofitted to work with matrix-based charging arrives at the parking lot, it aligns with the wireless charging pad. The system detects the vehicle and initiates the charging process. The monitoring platform updates the charging status in real-time, ensuring proper energy transfer.	EV Owner	EV arrives at the parking lot	The EV must be retrofitted with matrix-based charging capabilities. The parking lot must have an operational wireless charging system.	The EV successfully charges and updates charging status on the monitoring platform.
2	Vessel Charging	When an electric or hybrid vessel docks at the port, it connects to the charging station. The charging system verifies the connection and starts the smart charging process using OCPP commands. Charging progress and energy consumption data are recorded in real-time on the birdsEView platform.	Vessel Operator	The vessel docks at the port and requires charging	There must exist a retrofitted charger to allow the charging of vessels	The vessel successfully charges, and charging data is updated in the birdsEView platform.

4	Heavy-Duty/Buses Charging flexibility	When a heavy-duty electric vehicle or electric bus submits a charging request specifying the flexibility it can provide, the simulation environment recalculates the charging time and power profile accordingly.	CPO	Grid request	EV must be on at the charging point and has provided information about the possible flexibility.	The changed power and duration of charging of the specific EV vehicles that were activated.
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Steps-scenarios

Scenario							
Scenario name:		No.1: - Matrix-Based charging					
Step No.	Event	Name of process/activity	Description of process/activity	Service	Information producer (actor)	Information receiver (actor)	Information exchanged (IDs)
1.1	EV arrives at the parking lot	Retrofitted EV arrives at wireless charging station	The retrofitted electrical vehicle arrives at the designated parking lot and aligns with the wireless charging pad	REPORT	EV Owner	Charging Infrastructure Provider	IE-1.1
1.2	EV connection detected by the charging station	EV connection registration	The wireless charging system detects the vehicle's presence, confirms its compatibility with the technology used and his correct alignment with the charging pad	REPORT	Charging Infrastructure Provider	Monitoring Platform	IE-1.2; IE-1.3
1.3	Charging Session Requested	Charging Request Preferences submission	The EV user requests to start a charging session with the wireless charging system, expressing schedule and final SOC preferences	GET	EV Owner	Monitoring Platform	IE-1.4; IE-1.5
1.4	Charging station acknowledges request	Process charging request considering wireless energy transfer	The charging station verifies the request, processes it and authorizes wireless charging	CREATE	Monitoring Platform	Charging Infrastructure Provider	IE-1.6
1.5	Charging starts	Initiate wireless charging	The charging station begins transferring power wirelessly to the EV	EXECUTE	Charging Infrastructure Provider	EV	IE-1.7
1.6	Charging completes	End charging session	The EV reaches the SOC or the scheduled hour determined by the user, terminating the charging session	EXECUTE	Charging Infrastructure Provider	EV Monitoring Platform	IE-1.8

Scenario							
Scenario name:		No.2: - Vessel Charging					
Step No.	Event	Name of process/activity	Description of process/activity	Service	Information producer (actor)	Information receiver (actor)	Information exchanged (IDs)
2.1	Vessel docks at port	Vessel arrives at the port	The vessel docks at the port and aligns with the retrofitted charging station (to address vessel charging)	REPORT	Electric/Hybrid Vessel	Charger	IE-2.1
2.2	Connection Detected	Vessel connection is registered	The retrofitted charging infrastructure confirms the existence of a connection between it and the vessel and prepares it for the charging.	REPORT	Charger	BirdsEView Platform	IE-2.2
2.3	Charging Session Request	A request for charging the vessel is submitted	The vessel requests to start a charging session with the system, expressing schedule and final SOC preference	GET	Electric/Hybrid Vessel	BirdsEView Platform	IE-2.3; IE-2.4
2.4	Charging station acknowledges request	Process charging request	The charging station verifies the request and authorizes charging.	CREATE	BirdsEView Platform	Charger	IE-2.5
2.5	Charger Turns On	Charger activation via OCPP Protocol	The charging station turns on and begins supplying power via OCPP.	EXECUTE	Charger	Electric/Hybrid Vessel	IE-2.6
2.6	Charging in Progress	Power transfer in progress	The vessel starts receiving power from the charging station.	REPORT	Charger	Electric/Hybrid Vessel	IE-2.7
2.7	Charger Turns Off	Temporary deactivation of charger via OCPP Protocol	The charging system is temporarily turned off charging based on an energy management protocol while maintaining the session.	EXECUTE	Charger	Electric/Hybrid Vessel	IE-2.8
2.8	Charging Resumes	Resume power transfer	Once the energy management protocol allows it, the retrofitted charger resumes power transfer.	EXECUTE	Charger	Electric/Hybrid Vessel	IE-2.6; IE-2.7
2.9	Charging completes	End Charging Session	The vessel reaches the agreed charge/time scheduled, and the charging session is terminated.	EXECUTE	Charger	Electric/Hybrid Vessel BirdsEView Platform	IE-2.9

Scenario 3							
Scenario name:		No.3: - Heavy Duty/Buses charging flexibility					
Step No.	Event	Name of process/activity	Description of process/activity	Service	Information producer (actor)	Information receiver (actor)	Information exchanged (IDs)
3.1	Bus arrives at depot	Bus Arrival	Upon return from operation, the bus is plugged into the charging station.	REPORT	Driver	Charging Management System	IE-3.1
3.2	Bus is plugged into the V2G charger	Charging Connection	The bus is connected to a V2G-enabled charging station, enabling both charging and energy feedback.	EXECUTE	Battery Management System	Charging Management System	IE-3.2
3.3	CPO and DSO coordinate charging flexibility	V2G Session Initiation	The Charging Management System, under the supervision of the CPO, evaluates available flexibility, grid signals, and depot schedule. The CPO ensures service delivery and commercial alignment, while the CMS executes the technical coordination with the DSO.	EXECUTE	CPO/Charging Management System	Distribution System Operator	IE-3.3
3.4	Monitoring real-time data	Energy Monitoring	Real-time energy use and charging status are recorded and visualized via the Monitoring Platform for depot and grid operators.	REPORT	Charging Management System	Monitoring Platform	IE-3.4
3.5	Bus reaches the required charge level	V2G Charging Completion	Charging stops once the battery reaches the required SOC and any scheduled energy feedback to the grid is completed.	CLOSE	Battery Management System	Charging Management System	IE-3.5
3.6	Depot operation updates	Operational Feedback	Depot Manager reviews charging status and availability of buses for the next shift.	REPORT	Monitoring Platform	Depot Manager	IE-3.6

Information exchanged

Information exchanged – Scenario 1 (Matrix-Based charging)		
Information exchanged, ID	Name of information	Description of information exchanged
IE-1.1	Arrival Notification	Notification sent when the EV arrives at the wireless charging station, indicating its presence and alignment.
IE-1.2	Vehicle Detection Signal	Signal confirming that the vehicle has been detected by the charging station and is aligned for wireless charging.

IE-1.3	Technological Compatibility Confirmation	Confirmation that the EV is retrofitted to be compatible with the wireless charging technology in use.
IE-1.4	Charging Request	Request sent by the EV owner to initiate a charging session, including charging preferences
IE-1.5	User Preferences	Information specifying the user's preferred charging schedule and desired SOC at the end of the c charging session.
IE-1.6	Charging Authorization	Authorization granted by the monitoring platform to proceed with the wireless charging session.
IE-1.7	Charging Start Notification	Notification indicating that the charging process has started.
IE-1.8	Charging Completion Notification	Notification sent when the charging session ends, including details about the final SOC and charging duration, as well as the data recorded during the charging for further analysis.
IE-2.1	Docking Notification	A notification sent when the vessel docks at the port and aligns with the retrofitted charging station. Used to indicate the vessel presence and prepare a potential connection
IE-2.2	Vessel Detection Signal	Signal confirming physical connection between the retrofitted charging infrastructure and the vessel
IE-2.3	Charging Request	Request sent by the <i>Electric/Hybrid Vessel</i> to initiate a charging session, including the user preferences for the charging
IE-2.4	User Preferences	Information specifying the user's preferred charging schedule and desired SOC at the end of the c charging session
IE-2.5	Charging Authorization	Authorization granted by the birdsEView platform to proceed with the charging session.
IE-2.6	Charger Activation Command (ON)	A command sent to the charger to initiate power transfer via the OCPP protocol
IE-2.7	Energy Transferred Report	The actual energy delivered from the charger to the vessel during the session
IE-2.8	Charger Deactivation Command (OFF)	A command sent to the charger via OCPP protocol to temporarily stop the power transfer based on an energy management strategy
IE-2.9	Charging Completion Notification	Notification sent when the charging session ends, including details about the final SOC and charging duration, as well as the data recorded during the charging for further analysis.
IE-3.1	Arrival Notification	Notification sent when a bus arrives at the depot, indicating it is ready for charging.
IE-3.2	Charging Request ID	Request generated when the bus is connected to a charging station, initiating a charging session.
IE-3.3	Flexibility Coordination Data	Information exchanged between CPO and DSO on grid constraints, charging flexibility, and scheduling needs.
IE-3.4	Real-Time Energy Data	Live data on energy consumption, charging progress, and V2G activity reported to the Monitoring Platform.
IE-3.5	Charging Completion ID	Notification that the charging session (and any grid support event) has been completed.
IE-3.6	Operational Availability Update	Feedback to the Depot Manager about the charging status and next availability of the vehicle.

Common terms and definitions

<i>Common terms and definitions</i>	
Term	Definition
BirdsEView Platform	A centralized digital platform that collects and analyses data from EVSEs, vessels, grid and other infrastructure for monitoring and control.
Communication Protocol	Standardized rules that enable data exchange between devices, charging infrastructure and the grid.
DSO	Distribution system operator
EV	Electric vehicle
Electric Vehicle Supply Equipment (EVSE)	The equipment which delivers the energy responsible for charging the vehicles. This includes the chargers, the connectors and the control systems.
HDV	Heavy-duty vehicle
HLUC	High-level use case
HV	High voltage
Matrix-Based Charging	Wireless charging system that replaces traditional plug-in methods by utilizing a ground-embedded matrix to deliver power to the vehicle.
MV	Medium voltage
OCPP (Open Charge Point Protocol)	Communication standard that allows charging stations to communicate with a central system for monitoring, billing, and control.
PUC	Primary use case
Smart Charging	A charging approach that optimizes energy consumption by dynamically adjusting charging power based on grid conditions and pricing.
SOC	State of charge
SUC	Specialized use case
Vehicle-to-Grid (V2G)	A system in which EVs not only draw power from the grid but also return excess stored energy back to the grid to support energy demand balancing.
Communication Protocol	Standardized rules that enable data exchange between devices, charging infrastructure and the grid.

II.V HLUC5 – Smart charging in workplaces

Description of the use case

Name of the use case

Use case identification		
ID	Area/Domain(s)/Zone(s)	Name of use case
HLUC5	Area: energy system Domain: distribution system Zones: operation, station, field	Smart charging in workplaces

Version management

Version management			
Version No.	Date	Name of author(s)	Changes
0.0	05.09.24	Marzio Barresi (POLIMI)	First template provided
0.1	02.06.25	Lucas Pereira (IST-ID), Gustavo Miranda (IST-ID), Cindy Guzman (INESC-ID)	First draft of HLUC5
0.2	22.10.25	Marzio Barresi (POLIMI)	Final draft version of HLUC5

Scope and objectives of use case

Scope and objectives of use case	
Scope	The High-Level Use Case (HLUC) aims to evaluate innovative smart charging solutions for Electric Vehicle Supply Equipment (EVSE) at workplaces. Primarily emphasizing aspects as flexibility services, renewable energy integration and inclusion of dynamic pricing models based on distributor system operator (DSO) information in both countries, Portugal and Denmark. A key aspect of these use cases will be the testing and comparison of distributed and centralized versions of the services where distributed version can be applied. The following Primary Use Cases (PUCs) will be derived from this HLUC. “C” stands for centralized, whereas “D” stands for distributed: - PUC5.1C PUC5.1D – Maximization of Self-Consumption from RESs. Scope: The use case focuses on optimizing EV charging scheduling using predictive and control algorithms considering the presence of renewable energy sources (RESs) from solar photovoltaic (PV). - PUC5.2C PUC5.2D – Voltage and Frequency Control. Scope: The use case focuses on optimizing electric vehicle (EV) charging scheduling using predictive and control algorithms considering the need to stabilize voltage and frequency. - PUC5.3C PUC5.3D – Dynamic Pricing from DSO signals. Scope: The use case focuses on optimizing EV charging scheduling using predictive and control algorithms considering external price signals based on DSO information. The use case excludes the definition and validation of the price signals; price forecasting is also excluded from the use case.

	- PUC5.4C PUC5.4D – Multi-objective: PUC5.1 + PUC5.2 Scope: <i>The use case focuses on optimizing EV charging scheduling using predictive and control algorithms with conflicting objectives. More precisely this use case will consider the need to maximize self-consumption from RES, while maintaining the voltage and frequency in the accepted limits.</i> Six Specialized Use Cases (SUCs) will be derived according to demos: - SUC5.1a – Western Europe demo – Lisbon - SUC5.1b – Northern Europe demo – Slow charging demo - SUC5.2a – Northern Europe demo – Slow charging demo - SUC5.3a – Western Europe demo – Lisbon - SUC5.3b – Northern Europe demo – Slow charging demo - SUC5.4 – Northern Europe demo – Slow charging demo
Objective(s)	1) PUC5.1C PUC5.1D – Maximization of Self-Consumption from RESs. Objective: To develop and test, in the real-world testbed, distributed (and centralized) scheduling algorithms that maximizes the self-consumption from RESs, while ensuring that the EV charging objectives are met. 2) PUC5.2C PUC5.2D – Voltage and Frequency Control. Objective: To develop and test, in the real-world testbed, distributed (and centralized) scheduling algorithms that reduce the number of times that voltage and frequency PU values are outside the permitted ranges, e.g., $0.95 < V_{pu} < 1.05$ (medium voltage (MV)) $0.90 < V_{pu} < 1.1$ (low voltage (LV)). 3) PUC5.3C PUC5.3D – Dynamic Pricing from DSO signals. Objective: To develop and test, in the real-world testbed, distributed (and centralized) scheduling algorithms that reduce the cost of charging by shifting charging to periods of lower prices. 4) PUC5.4C PUC5.4D – Multi-objective: PUC5.1 + PUC5.2 Objective: To develop and test, in the real-world testbed, distributed (and centralized) scheduling algorithms that is able to balance self-consumption and voltage/frequency. Additionally, the objective includes identifying key trade-offs between the two competing objectives.

Narrative of use case

Narrative of use case	
Short description	This use case, conducted in Portugal and Denmark, focuses on developing and testing centralized and distributed smart charging algorithms for EVs. The goal is to maximize self-consumption of renewable energy and minimize charging costs by aligning EV charging with periods of high renewable availability and low electricity prices. In Portugal, the use case will focus on EV charging through forecasting, monitoring, and control tools that will be made available for both parking operators and EV users. In Denmark, the system will be tested in a rural setting to evaluate its role in grid stability and the impact of dynamic pricing on charging behaviour. Considering the objectives and solutions tested in this use case, there are several synergies with other AHEAD use cases. Namely, HLUC1 (new demand response and flexibility contracts), HLUC2 (charging stations with low-rated capacity), UC9 (coordinated charging via charge point operators), HLUC10 (coordinated charging in a virtual power plant setup), and HLUC11 (activation of flexibility services by DSOs).
Complete description	This use case, in Portugal, aims to develop and validate scheduling algorithms in both distributed and centralized that enhance self-consumption from RESs and minimize charging costs by leveraging periods of lower electricity prices. The smart charging algorithms will optimize charging schedules to align EV energy demand with available renewable generation, reducing dependency on grid electricity and enhancing sustainability. The overall framework includes the deployment and continuous monitoring of EV energy consumption, the assessment and regulation of charging station performance, and the implementation of control mechanisms for charging stations. Furthermore, the aggregation platform will deliver forecasting analytics and charging optimization data to a dashboard for parking lot operators, while also providing an intuitive graphical interface for EV owners.

In Denmark, testing will take place for leveraging existing infrastructure to evaluate distributed versus centralized flexibility services for network operators. The study will focus on balancing grid stability (voltage and frequency control) with maximizing self-consumption of RESs. Additionally, dynamic pricing mechanisms based on DSO data will be implemented in collaboration with industry partners to assess their impact on charging behaviour and infrastructure utilization. Ultimately, the anticipated outcomes of this UC include self-consumption maximization by optimizing charging schedules to align EV energy demand with available renewable generation, thereby reducing reliance on grid electricity and enhancing sustainability. Additionally, cost optimization will be achieved through dynamic charging schedules based on real-time electricity prices, shifting consumption to lower-cost periods while maintaining user requirements.

Related primary use case

ID	Name	Description
PUC5.1C PUC5.1D	Maximization of Self-Consumption from RESs	This use-case focuses on maximizing self-consumption from RESs by developing and testing distributed and centralized scheduling algorithms in a real-world testbed. This will be achieved by using predictive control and control algorithms that adjust EV charging considering the presence of RESs while ensuring the EV charging objectives are met.
PUC5.2C PUC5.2D	Voltage and Frequency Control	The voltage and frequency fluctuations will be addressed by implementing real-time adjustments to EV charging loads based on grid conditions. The system will integrate voltage and frequency monitoring with predictive control algorithms, helping stabilize voltage and frequency variations, ensuring grid reliability.
PUC5.3C PUC5.3D	Dynamic Pricing from DSO signals	PUC5.3 aims to reduce EV charging costs through dynamic pricing by incorporating signals from the DSO into charging schedules. By collecting pricing signals from the DSO, cost-optimization algorithms will be developed, implementing adaptive charging schedules. By aligning charging activities with lower price periods, both the users and the grid will benefit.
PUC5.4C PUC5.4D	Multi-objective: PUC5.1 + PUC5.2	Here a multi-objective optimization model is explored. This model considers both maximisation self-consumption (PUC5.1) and voltage and frequency control (PUC5.2). With its implementation in a real-world testbed, it will be identified the key trade-offs between these two conflicting objectives.

Related specialized use case

ID	Name	Description
SUC5.1a	Western Europe demo – Lisbon	At EDP parking lot in Lisbon, there are currently 64 EV chargers, with plans to extend that number up to 67. These chargers operate alongside other energy consumers, including office buildings and an electric bus. Since the PV generation at the site supplies power to all these loads, there are times when it is insufficient to support all charging needs, limiting the availability of the chargers. In this context, a smart scheduling solution will be studied for a real-world application in order to maximize self-consuming from RESs while ensuring EV charging objectives are met, which will reduce the stress on the grid during peak hours and enable a more efficient use of the PV. Additionally, by optimizing charging strategies around the introduction of RESs, it could expand PV capacity.
SUC5.1b	Nordic Europe demo – Slow charging demo	The parking lot at DTU Risø has multiple EVSEs of different brands. The chargers operate alongside the office buildings and are connected to SYSLAB, including RESs. The chargers can be controlled in a way to maximise self-consumption.
SUC5.2a	Nordic Europe demo – Slow charging demo	The parking lot at DTU Risø has multiple EVSEs of different brands. The chargers operate alongside the office buildings and are connected to SYSLAB, including RESs.

		The chargers can be controlled in a way to contribute to voltage and frequency stability.
SUC5.3a	Western Europe demo – Lisbon	Currently, only four of chargers in the parking lot (this number will increase to seven in the future) are fully controllable, allowing for direct adjustments to the charging schedules. The remaining 60 chargers are managed by a third-party application. To reduce the charging costs and promote implicit demand response on the parking lot, a smart charging solution will be studied considering its usual charging patterns alongside dynamic pricing signals from the DSO. By collecting electricity price signals, the system will develop and implement adaptive charging schedules that align EV charging with periods of lower electricity costs.
SUC5.3b	Nordic Europe demo – Slow charging demo	The parking lot at DTU Risø has multiple EVSEs of different brands. The chargers operate alongside the office buildings and are connected to SYSLAB, including RESs. The chargers can be controlled in a way to respond to dynamic price signals.
SUC5.4	Nordic Europe demo – Slow charging demo	The parking lot at DTU Risø has multiple EVSEs of different brands. The chargers operate alongside the office buildings and are connected to SYSLAB, including RESs. The chargers can be controlled in a way to contribute to multiple objectives at once.

Key performance indicators (KPI)

Key performance indicators			
ID	Name	Description	Reference to mentioned use case objectives
SUC 5.1a			
KPI5.1	Self-Consumption Rate	The percentage of EV charging energy that comes directly from RES.	PUC5.1C PUC5.1D – Maximization of Self-Consumption from RESs.
KPI5.2	PV Utilization Efficiency	The ratio of PV energy used in for EV charging compared to the total of PV generated.	PUC5.1C PUC5.1D – Maximization of Self-Consumption from RESs.
KPI5.3	Grid Load Reduction	The percentage of reduction in grid's peak power.	PUC5.1C PUC5.1D – Maximization of Self-Consumption from RESs.
KPI5.4	Number of EV Chargers Supplied by RES	The number of EV chargers that are actively using RES energy as their primary power source.	PUC5.1C PUC5.1D – Maximization of Self-Consumption from RESs.
SUC5.1b			
KPI5.5	Self-Consumption Rate	The percentage of EV charging energy that comes directly from RES.	PUC5.1C PUC5.1D – Maximization of Self-Consumption from RESs.
KPI5.6	PV Utilization Efficiency	The ratio of PV energy used in for EV charging compared to the total of PV generated.	PUC5.1C PUC5.1D – Maximization of Self-Consumption from RESs.
KPI5.7	Grid Load Reduction	The percentage of reduction in grid's peak power.	PUC5.1C PUC5.1D – Maximization of Self-Consumption from RESs.
KPI5.8	Number of EV Chargers Supplied by RES	The number of EV chargers that are actively using RES energy as their primary power source.	PUC5.1C PUC5.1D – Maximization of Self-Consumption from RESs.
SUC5.2a			

KPI5.9	Delay time	The time required to adjust the power setpoint	PUC5.2C PUC5.2D – Voltage and Frequency Control
KPI5.10	Demand response accuracy	The accuracy of the active/reactive power adjustment	PUC5.2C PUC5.2D – Voltage and Frequency Control
SUC5.3a			
KPI5.11	Charging Cost Savings	Percentage of cost savings achieved by aligning charging with lower electricity price periods.	PUC5.3C PUC5.3D – Dynamic Pricing from DSO signals
KPI5.12	Grid Load Reduction	The percentage of reduction in grid's peak power.	PUC5.3C PUC5.3D – Dynamic Pricing from DSO signals
KPI5.13	Controllable Charger Utilization Rate	The efficiency of the four/seven fully controllable chargers in executing cost-optimized schedules if compared to the standard ones (only turn on or off)	PUC5.3C PUC5.3D – Dynamic Pricing from DSO signals
KPI5.14	Charging Duration Variability	How much did the cost-optimized scheduling affect the total charging time for each session.	PUC5.3C PUC5.3D – Dynamic Pricing from DSO signals
SUC5.3b			
KPI5.15	Charging Cost Savings	Percentage of cost savings achieved by aligning charging with lower electricity price periods.	PUC5.3C PUC5.3D – Dynamic Pricing from DSO signals
KPI5.16	Grid Load Reduction	The percentage of reduction in grid's peak power.	PUC5.3C PUC5.3D – Dynamic Pricing from DSO signals
KPI5.17	Controllable Charger Utilization Rate	The efficiency of the four/seven fully controllable chargers in executing cost-optimized schedules if compared to the standard ones (only turn on or off)	PUC5.3C PUC5.3D – Dynamic Pricing from DSO signals
KPI5.18	Charging Duration Variability	How much did the cost-optimized scheduling affect the total charging time for each session.	PUC5.3C PUC5.3D – Dynamic Pricing from DSO signals
SUC5.4a			
KPI5.19	Combination of previous KPI	Combination of the previously explained KPIs from SUC1, SUC2 and SUC3	PUC5.1C PUC5.1D – Maximization of Self-Consumption from RESs PUC5.2C PUC5.2D – Voltage and Frequency Control PUC5.3C PUC5.3D – Dynamic Pricing from DSO signals

[Use case conditions](#)

Use case conditions	
Assumptions	
SUC 5.1, SUC 5.2, SUC 5.3, SUC5.4	
- A sufficient number of EVs should regularly use the parking lots for charging in both locations. - The infrastructure can support both distributed and centralized flexibility approaches.	
Prerequisites	
SUC 5.1, SUC5.2, SUC5.3, SUC5.4	
- A fully functional network of charging stations. - A robust EMS to manage and monitor the charging operations.	

- Direct access to simulated RES generation profiles for testing the impact of renewable energy on charging operations. - A reliable communication network linking all EVSEs with the EMS, ensuring data exchange.
SUC 5.2
- Voltage and frequency measurements are available near real-time (ideally sub-minute)

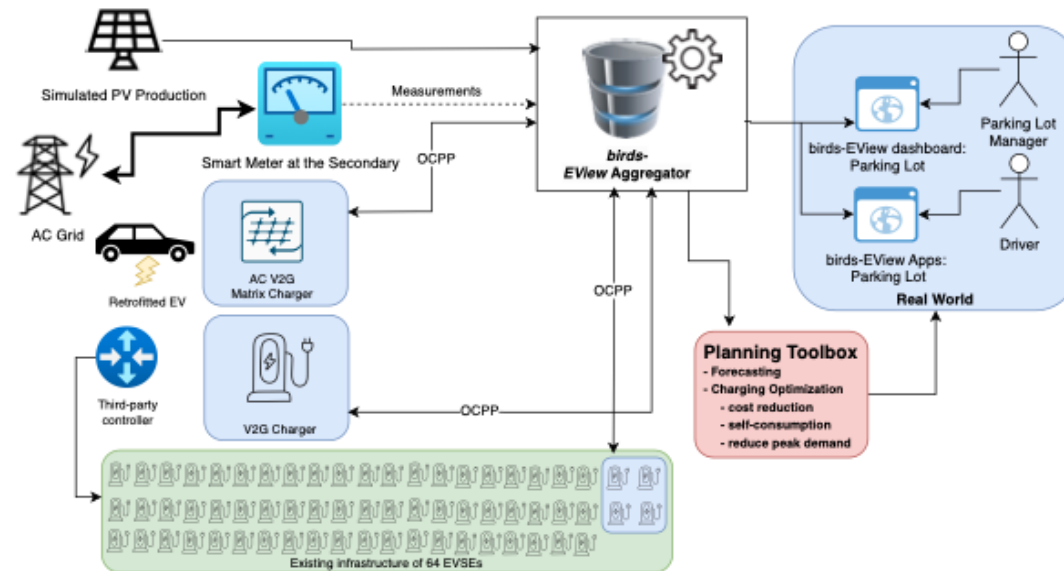
[Further information to the use case for classification/mapping](#)

Classification information
Relation to other use cases
• HLUC5 is directly related to HLUC6 (Utilization rate vs charging prices), to HLUC9 (evaluation of user-engagement in charging strategies) and to HLUC11 (use case focused on activation of flexibility services by DSOs).
Level of depth
HLUC5 - Smart charging in workspaces • PUC5.1C PUC5.1D – Maximization of Self-Consumption from RESs. • PUC5.2C PUC5.2D – Voltage and Frequency Control. • PUC5.3C PUC5.3D – Dynamic Pricing from DSO signals. • PUC5.4C PUC5.4D – Multi-objective: PUC5.1 + PUC5.2 • SUC5.1a – Western Europe demo – Lisbon • SUC5.1b – Nordic Europe demo – Slow charging demo • SUC5.2a – Nordic Europe demo – Slow charging demo • SUC5.3a – Western Europe demo – Lisbon • SUC5.3b – Nordic Europe demo – Slow charging demo • SUC5.4 – Nordic Europe demo – Slow charging demo
Prioritisation
Medium to high priority to AHEAD due to the considerable changes that will occur in private, public and semi-public parking lots in result of massive electrification of vehicles. It is important to stress that most of these infrastructures were building many years ago (sometimes decades), hence the existing electrical infrastructure is often rather limited.
Generic, regional or national relation
This is general use case as these infrastructures are ubiquitous, especially urban areas.
Nature of the use case
This is a technical use case that aims to assess the role of smart charging in minimizing the costs of infrastructural changes in existing parking lots. Moreover, the use cases will also serve to help planning the electrical infrastructure of future parking lots.
Further keywords for classification
Charging with limited power, charging power sharing, flexibility, infrastructure stability, AI-driven planning and operation

Diagram of use case

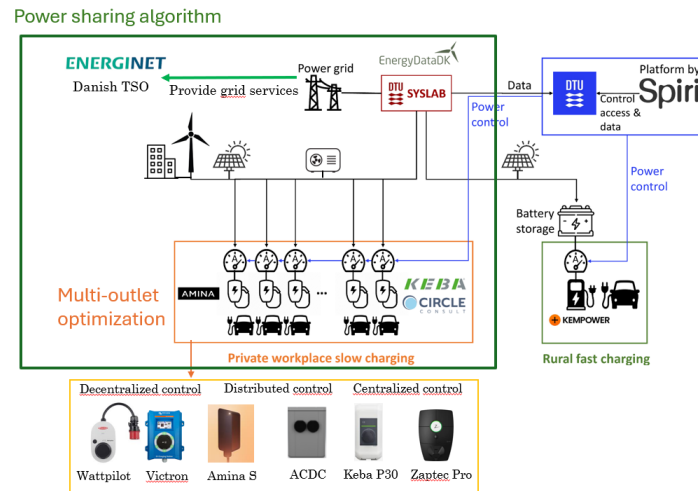
Diagram(s) of use case

SUC5.1a/ SUC5.3a: Western Europe demo – Lisbon



SUC5.1b/SUC5.2a/SUC5.3b/SUC5.4: Nordic Europe demo – Slow charging demo

Danish demo: Location 2



Technical details

Actors

Actors			
Grouping		Group description	
Maximization of Self-Consumption from RESs.		This group includes human and non-human actors for the use case related to self-consumption from renewable energy solutions (PUC5.1 - SUC5.1)	
Actor name	Actor type	Actor description	Further information specific to this use case
Electric Vehicle Owners/Users	Human Actor	End-users who charge their/company EV at the parking lot.	Their charging schedules will be impacted by the smart scheduling solutions with all the impact that it could have in the charging.
Renewable Energy Provider	System Actor	Supplies green energy to the parking lot.	Supply clean energy for EV charging and integrate their generation profiles into grid simulations.

Distribution System Operator (DSO)	System Actor	Responsible for monitoring and controlling the electrical grid infrastructure. It interacts with the system to assess the impact of proposed charging stations on the grid and optimize resource allocation.	Ensures that the integration with other sources of energy is feasible and aligns with the grid capacity.
Parking Lot Energy Management System (EMS)	System Actor	Software system responsible for the motorization and optimization of the distributed energy.	Implements scheduling algorithms made to prioritize RES, when available.
Smart Scheduling Algorithm	System Actor	A control algorithm developed to optimize charging schedules to maximize RES consumption.	Uses predictive control to adjust EV charging in real-time based on RES availability.
Smart Charging Station	System Actor	Physical EVSE delivering electricity to the vehicle, connected with EMS and scheduling logic.	Execute start, adjust, and stop charging commands, and reports charging status to EMS.

Actors			
Grouping		Group description	
Voltage and Frequency Control		This group includes the actors responsible for maintaining grid stability during EV charging in the parking lot. (PUC5.2 - SUC5.2)	
Actor name	Actor type	Actor description	Further information specific to this use case
Electric Vehicle Owners/Users	Human Actor	End-users who charge their/company EV at the parking lot.	Their charging may be curtailed or delayed when grid stability services are activated.
Distribution System Operator (DSO)	System Actor	Provides grid stability requirements and monitors voltage/frequency parameters.	Requests corrective actions when limits are exceeded.
Parking Lot Energy Management System (EMS)	System Actor	Supervises charging sessions and executes control signals to charging stations.	Integrates V/F regulation constraints into scheduling.
Voltage/Frequency Regulation Algorithm	System Actor	Control algorithm designed to monitor grid conditions and adjust charging dynamically.	Implements corrective actions (e.g., reduction, stop, restart of charging).
Smart Charging Station	System Actor	Physical charging infrastructure capable of responding to commands from EMS.	Adjusts charging rate or suspends charging based on control signals.

Actors	
Grouping	Group description

Dynamic Pricing from DSO signals.		This group includes human and non-human actors for the use case related to Dynamic Pricing from DSO signals (PUC5.3a - SUC5.3)	
Actor name	Actor type	Actor description	Further information specific to this use case
Electric Vehicle Owners/Users	Human Actor	End-users who charge their/company EV at the parking lot.	Their charging schedules will be impacted by the smart scheduling solutions with all the impact that it could have in the charging.
Distribution System Operator (DSO)	System Actor	Responsible for monitoring and controlling the electrical grid infrastructure. It interacts with the system to assess the impact of proposed charging stations on the grid and optimize resource allocation.	In this use case, specifically, will provide the price signals. These will be used to develop the algorithms for the cost-optimized scheduling.
Parking Lot Energy Management System (EMS)	System Actor	Software system responsible for the motorization and optimization of the distributed energy.	Integrates DSO price signals to schedule charging during cheaper periods, reducing costs.
Cost-Optimization Algorithm	System Actor	An adaptive control algorithm that schedules charging based on pricing data.	Aligns charging with lower electricity price periods to benefit the price charged and reduce peak demand on the grid.
Third-Party Charging Management System	System Actor	The system responsible for the managing the non-fully-controllable chargers (turn on/off based on PV availability).	Receives control commands from the EMS to align their operation with optimized schedules.
Smart Charging Station	System Actor	Physical charging infrastructure capable of responding to commands from EMS.	Detects connection, executes charging, and provides completion notifications.

Actors			
Grouping		Group description	
Multi-objective Optimization.		This group includes actors balancing RES maximization and V/F stability. (PUC5.4 – SUC 5.4)	
Actor name	Actor type	Actor description	Further information specific to this use case
Electric Vehicle Owners/Users	Human Actor	End-users who charge their/company EV at the parking lot.	Their charging schedules will be impacted by the smart scheduling solutions with all the impact that it could have in the charging.
Distribution System Operator (DSO)	System Actor	Provides grid status and ensures stability.	Supplies both grid constraints and potential signals for RES integration.
Parking Lot Energy Management System (EMS)	System Actor	Software system responsible for the motorization and optimization of the distributed energy.	Balances between RES and V/F objectives.
Smart Scheduling Algorithm	System Actor	Algorithm designed to maximize RES use.	Integrates RES generation data and forecasts.
Voltage/Frequency Regulation Algorithm	System Actor	Ensures grid operational limits are respected.	Works jointly with the RES optimization algorithm.
Smart Charging Station	System Actor	Executes charging commands.	Adjusts power dynamically under EMS supervision.

Step-by-step analysis of use case

Overview of scenarios

Scenario conditions						
No.	Scenario name	Scenario description	Primary actor	Triggering event	Pre-condition	Post-condition
1	Maximize self-consumption from RES	Once an EV arrives, it is plugged into a charger in the parking lot. The Parking Lot EMS, receiving real-time data on RES generation and schedules charging to align with high availability. The smart scheduling algorithm ensures the EV charges primarily from RES while meeting the user's charging needs.	Electric Vehicle Owners/User; Parking Lot EMS; Smart Scheduling Algorithm	Availability of RES	Renewable energy sources are producing energy and the EVs are available for charging.	Charging schedules are adjusted to maximize RES utilization and a possible stress on the grid is mitigated.
2	Voltage and Frequency Control	When multiple EVs arrive at the parking lot and begin charging simultaneously. The Parking Lot EMS monitors voltage and frequency fluctuations in real-time and adjusts charging rates dynamically to prevent grid instability. If voltage or frequency deviates from permitted limits, charging is momentarily reduced or completely turned off among vehicles (depending on the charger the vehicle is plugged).	Electric Vehicle Owners/User; Parking Lot EMS; Voltage / Frequency Regulation Algorithm; DSO	Voltage or frequency out of limits	The EV is connected and has accepted to participate in the service	Charging schedules are adjusted until Voltage or Frequency are regulated, or until the duration of the service as elapsed.
3	Dynamic Pricing	An EV arrives at the parking lot and plugs in their vehicle. The Parking Lot EMS retrieves the DSO price signals history and schedules charging to align with lower-cost periods. If the price is high at the moment, charging is delayed or slowed down (depending on the charger the vehicle is plugged in) until the price drops.	EV Owner, Parking Lot EMS; Cost-Optimization Algorithm; DSO	A request for a lower-cost charging	DSO price signals are available and EV is plugged in and ready to charge.	The EV is charged at the lowest possible cost at the time available for charging, reducing electricity expenses for parking lot owners.
4	Multi-objective	An EV arrives and is plugged in. The Parking Lot EMS evaluates the need to maximize self-consumption from RES while maintaining voltage and frequency stability. The system balances these two objectives by adjusting charging rates dynamically, prioritizing RES when possible but ensuring grid stability is not compromised.	EV Owner, Parking Lot EMS; Smart Scheduling Algorithm; Voltage / Frequency Regulation Algorithm; DSO	Availability of RES and voltage and/or frequency are out of limits	Renewable energy sources are producing energy and the EVs are available for charging/discharging and have accepted to participate in the service	Charging schedules are adjusted to maximize RES while temporary adjustments are also in place to mitigate voltage or frequency issues.

[Steps-scenarios](#)

Scenario							
Scenario name:		No. 1 – Maximize self-consumption from RES)					
Step No.	Event	Name of process/activity	Description of process/activity	Service	Information producer (actor)	Information receiver (actor)	Information exchanged (IDs)
1.1	EV Arrival at the parking lot	EV arrives at charging station	The EV arrives at the parking facility and driver parks in one of the available charging locations	REPORT	Electric Vehicle Owner/User	Smart Charging Station	IE-1.1
1.2	Connection Detected	Register EV connection	The charging infrastructure confirms the existence of a connection between it and the electrical vehicle and prepares it.	CREATE	Smart Charging Station	Parking Lot EMS	IE-1.2
1.3	Charging Session Request	Charging Request Preferences submitted	The EV requests charging based on its battery status and energy needs (desired state of charge (SOC), departure time) and EV's current SOC).	REPORT	Electric Vehicle Owner/User	Parking Lot EMS	IE-1.3
1.4	RES and Grid Data Exchange	Input for optimization	The Renewable Energy Provider and DSO send RES generation data (real-time & forecast) and grid status to the EMS.	REPORT	Renewable Energy Provider, DSO	Parking Lot EMS	IE-1.4; IE-1.5; IE-1.6
1.5	Charging station acknowledges request	Process charging request considering RES	The Smart Scheduling Algorithm processes the charging request, checks RES availability, and calculates an optimal charging schedule according to EV owner needs.	EXECUTE	Smart Scheduling Algorithm	Parking Lot EMS	IE-1.7
1.6	Charging starts	Initiate charging	The Parking Lot EMS begins charging the EV according to the calculated schedule prioritizing RES utilization.	EXECUTE	Parking Lot EMS	Smart Charging Station	IE-1.8
1.7	Charging progresses	Adjust charging schedule	The charging station changes the charging rate of power to be delivered to the vehicle to maximize the usage of renewable energy.	CHANGE	Parking Lot EMS /Smart Scheduling Algorithm	Smart Charging Station	IE-1.9
1.8	Charging completes	End charging session	Whenever the EV reaches its desired state of charge or at user-defined end time, the charging session ends.	EXECUTE	Smart Charging Station	Electric Vehicle Owner/User	IE-1.10

Scenario							
Scenario name:		No. 2 – Voltage and Frequency control					
Step No.	Event	Name of process/activity	Description of process/activity	Service	Information producer (actor)	Information receiver (actor)	Information exchanged (IDs)

2.1	EV Arrival at the parking lot	EV arrives at charging station	The EV arrives at the parking facility and driver parks in one of the available charging locations	REPORT	Electric Vehicle Owner/User	Smart Charging Station	IE-1.1
2.2	Connection Detected	Register EV connection	The charging infrastructure confirms the existence of a connection between it and the electrical vehicle and prepares it.	CREATE	Smart Charging Station	Parking Lot EMS	IE-1.2
2.3	Charging Session Request	Charging Request Preferences submitted	The EV requests charging based on its battery status and energy needs (desired state of charge (SOC), departure time) and EV's current SOC).	REPORT	Electric Vehicle Owner/User	Parking Lot EMS	IE-1.3
2.4	Charging starts	Initiate charging	The Parking Lot EMS begins charging the EV.	EXECUTE	Parking Lot EMS	Smart Charging Station	IE-1.8
2.5	Grid parameters monitored	V/F monitoring	The EMS and algorithm monitor real-time grid data for voltage and frequency deviations.	GET	DSO	Parking Lot EMS / V/F Algorithm	IE-1.6
2.6	Instability detected	Trigger corrective actions	When deviations exceed limits, the V/F algorithm decides corrective measures.	EXECUTE	V/F Algorithm	Parking Lot EMS	IE-2.1
2.7	Corrective command applied	Charging adaptation	EMS commands charging stations to reduce/stop charging.	CHANGE	Parking Lot EMS	Smart Charging Station	IE-1.9
2.8	Grid stability restored	Resume or adjust charging	Once conditions normalize, EMS gradually resumes charging.	CHANGE	Parking Lot EMS	Smart Charging Station	IE-1.9
2.9	Charging complete	End charging session	Whenever the EV reaches its desired state of charge or at user-defined end time, the charging session ends.	EXECUTE	Smart Charging Station	Electric Vehicle Owner/User	IE-1.10

Scenario							
Scenario name:		No. 3 – Dynamic pricing					
Step No.	Event	Name of process/activity	Description of process/activity	Service	Information producer (actor)	Information receiver (actor)	Information exchanged (IDs)
3.1	EV Arrival at the parking lot	EV arrives at charging station	The EV arrives at the parking facility and driver parks in one of the available charging locations	REPORT	Electric Vehicle Owner/User	Smart Charging Station	IE-1.1
3.2	Connection Detected	Register EV connection	The charging infrastructure confirms the existence of a connection between it and the electrical vehicle and prepares it.	CREATE	Smart Charging Station	Parking Lot EMS	IE-1.2

3.3	Charging Session Request	Charging Request Preferences submitted	The EV requests charging based on its battery status and energy needs (desired state of charge (SOC), departure time) and EV's current SOC).	REPORT	Electric Vehicle Owner/User	Parking Lot EMS	IE-1.3
3.4	Price Signal Data Exchange	Input for optimization	The DSO provides current and forecasted price signals to the EMS.	REPORT	DSO	Parking Lot EMS	IE-3.1; IE-3.2
3.4	Charging station acknowledges request	Process charging request considering Pricing Signals	The Cost-Optimization Algorithm processes the request and EMS inputs, analyses current and forecasted price signals from the DSO and calculates an optimal charging scheduling period to minimize costs at the same time it meets the user's need	EXECUTE	Cost-Optimization Algorithm	Parking Lot EMS	IE-3.3
3.5	Charging starts	Cost-optimized scheduling	The Parking Lot EMS starts the EV charging process, following the schedule calculated by the Cost-Optimization Algorithm	EXECUTE	Parking Lot EMS/ Cost-Optimization Algorithm	Smart Charging Station	IE-1.8
3.6	Third-party coordination	Third-party charging system integration	For the non-fully controllable chargers, the system coordinates with their third-party management system, turning them on or off, depending on the " <i>Cost-Optimized Charging Schedule</i> ". With this it optimizes their usage based on price signals	EXECUTE	Parking Lot EMS/ Cost-Optimization Algorithm	Third-Party Charging Management System	IE-3.4
3.7	Charging progresses	Adjust charging schedule	The charging station changes the charging rate of power to be delivered to the vehicle to be according to the best schedule for a lower-price charging	CHANGE	Parking Lot EMS/ Cost-Optimization Algorithm	Smart Charging Station	IE-3.5
3.8	Charging complete	End charging session	Whenever the EV reaches its desired state of charge or at user-defined end time, the charging session ends.	EXECUTE	Smart Charging Station	Electric Vehicle Owner/User	IE-1.10

Scenario							
Scenario name:		No. 4 – Multi-objective					
Step No.	Event	Name of process/ activity	Description of process/ activity	Service	Information producer (actor)	Information receiver (actor)	Information exchanged (IDs)
4.1	EV Arrival at the parking lot	EV arrives at charging station	The EV arrives at the parking facility and driver parks in one of the available charging locations	REPORT	Electric Vehicle Owner/User	Smart Charging Station	IE-1.1
4.2	Connection Detected	Register EV connection	The charging infrastructure confirms the existence of a connection between it and the electrical vehicle and prepares it.	CREATE	Smart Charging Station	Parking Lot EMS	IE-1.2

4.3	Charging Session Request	Charging Request Preferences submitted	The EV requests charging based on its battery status and energy needs (desired state of charge (SOC), departure time) and EV's current SOC).	REPORT	Electric Vehicle Owner/User	Parking Lot EMS	IE-1.3
4.4	RES availability monitored	RES integration check	Smart Scheduling Algorithm collects RES data and forecasts.	GET	Parking Lot EMS	Smart Scheduling Algorithm	IE-1.4; IE-1.5
4.5	Grid conditions monitored	Grid status monitoring	EMS receives real-time grid status from DSO (voltage/frequency).	GET	DSO	Parking Lot EMS / V/F Algorithm	IE-1.6
4.6	Optimization decision	Multi-objective optimization	Smart algorithms combine RES availability and grid stability constraints to generate a balanced charging schedule.	EXECUTE	Smart Scheduling Algorithm + V/F Algorithm	Parking Lot EMS	IE-4.1
4.7	Charging control applied	Coordinated charging	EMS instructs charging stations with adapted charging profiles.	EXECUTE	Parking Lot EMS	Smart Charging Station	IE-1.8
4.8	Charging complete	End charging session	Whenever the EV reaches its desired state of charge or at user-defined end time, the charging session ends.	EXECUTE	Smart Charging Station	Electric Vehicle Owner/User	IE-1.10

Information exchanged

<i>Information exchanged</i>		
<i>Information exchanged, ID</i>	<i>Name of information</i>	<i>Description of information exchanged</i>
IE-1.1	Vehicle Arrival Notification	Notification that a vehicle has arrived at a charging station with identifiers
IE-1.2	Connection Verification Data	Confirmation that a physical connection between the EV and the charging point has been successfully established.
IE-1.3	User Charging Parameters	User-defined preferences including desired state of charge, departure time, and current battery status required for scheduling.
IE-1.4	Real-time RES Availability	Up-to-date data on renewable energy generation. This includes RES data history.
IE-1.5	RES Generation Forecast	Forecasted renewable energy generation data needed to optimize the charging schedule.
IE-1.6	Grid Status Parameters	Current grid conditions and constraints relevant to optimizing the charging process.
IE-1.7	Optimized Charging Schedule for RES utilization	Calculated schedule that maximizes renewable energy utilization while meeting the user's charging requirements.
IE-1.8	Charging Start Command	Instruction from the EMS to the Smart Charging Station to initiate the charging session according to the optimized schedule.
IE-1.9	Schedule Adjustment Parameters (RES)	Parameters for modifying the charging schedule based on smart algorithm.
IE-1.10	Charging Completion Notification	Notification that the charging process has completed, including final battery status and session details.

IE-2.1	Instability Event Report	Notification from the V/F Regulation Algorithm to EMS that voltage/frequency limits have been exceeded and corrective actions are required.
IE-3.1	Current Price Signal Data	Real-time electricity price information from the DSO used to optimize the charging schedule for cost efficiency.
IE-3.2	Price Forecast Data	Predicted electricity price information for upcoming time periods to enable advance cost optimization planning.
IE-3.3	Cost-Optimized Charging Schedule	Calculated schedule that minimizes charging costs while meeting the user's charging requirements and timing constraints.
IE-3.4	Third-Party Control Commands	Instructions sent to third-party charging management system to control the non-fully controllable chargers based on price optimization.
IE-3.5	Schedule Adjustment Parameters (Price)	Parameters which modify the charging process based on the Cost-Optimized Charging Schedule
IE-4.1	Multi-Objective Charging Schedule	Optimized charging schedule that balances renewable energy utilization with voltage/frequency stability requirements, ensuring both user needs and grid constraints are respected.

Common terms and definitions

Common terms and definitions	
Term	Definition
DSO	Distribution system operator
EMS	Energy management system
EV	Electric vehicle
Electric Vehicle Supply Equipment (EVSE)	The equipment which delivers the energy responsible for charging the vehicles. This includes the chargers, the connectors and the control systems.
HLUC	High-level use case
LV	Low voltage
MV	Medium voltage
Peak Load	The highest level of electricity demand within a specific period.
PUC	Primary use case
PV	Photovoltaic
Smart Charging	A charging approach that optimizes energy consumption by dynamically adjusting charging power based on grid conditions and pricing.
SOC	State of charge
SUC	Specialized use case

II.VI HLUC6 – Smart charging at depots

Description of the use case

Name of the use case

Use case identification		
ID	Area/Domain(s)/Zone(s)	Name of use case
HLUC6	Area: Grid Domain: Distribution Systems Zones: Field, Market	Smart charging at the depots

Version management

Version management			
Version No.	Date	Name of author(s)	Changes
0.0	05.09.24	Marzio Barresi (POLIMI)	First template provided
0.1	02.06.25	Hasnain Salman (A2A), Alessandro Cirocco (A2A), Blaž Dobravec (EG), Lenart Ribnikar (EG)	First draft of HLUC6
0.2	22.10.25	Marzio Barresi (POLIMI)	Final draft version of HLUC6

Scope and objectives of use case

Scope and objectives of use case	
Scope	The High-Level Use Case (HLUC) focuses on optimizing the charging of heavy-duty electric vehicles (HDV) and public transport electric buses, thereby improving grid utilization in urban areas through smart depot charging methods. The three scenarios address different levels of charging optimization, from uncoordinated charging to smart charging and vehicle-to-grid (V2G) integration and HDV charging simulation. Four Primary Use Cases (PUCs) will be derived from this HLUC. 1. PUC6.1: Business as Usual Charging The first scenario covers the traditional, uncoordinated charging process, where buses charge on a first-come, first-served basis without considering grid constraints or optimization. The scope includes monitoring the energy consumption of battery electric buses (BEBs), tracking charging station utilization, and identifying inefficiencies in the charging process. 2. PUC6.2: Electric Bus Smart Charging The second scenario expands the scope to include smart charging techniques. It involves data acquisition from the Distribution System Operator (DSO), public transport operators, and charging management systems (CMS) etc. The scope includes optimizing charging schedules based on factors such as state of charge (SOC), grid demand, and departure schedules. This ensures that charging is performed in a cost-effective and grid-friendly manner.

	3. PUC6.3: Electric Bus Smart Charging with V2G Integration The third scenario further extends the scope by incorporating bidirectional energy flows through V2G technology. This scenario focuses on utilizing electric buses as grid assets, allowing energy to be withdrawn from or injected into the grid based on demand fluctuations. The scope includes grid stabilization, peak shaving, and increased renewable energy utilization, making battery electric buses charging more sustainable and flexible. 4. PUC6.4 Simulating Heavy Duty Electric Vehicle Charging This scenario considers the entire fleet of electric vehicles (EVs) (HDVs, buses, and cars). Charging is simulated and activated based on time-series consumption data from the primary transformer station, obtained via the SCADA system. The objective is to design a smart charging system capable of dynamically recalculating charging power levels and durations for all EVs in the depot when requested. Two Specialized Use Cases (SUCs) will be derived according to demo site: ▪ SUC6.1 – Southern Europe demo – Milan ▪ SUC6.2 – Southern Europe demo – Kranj
Objective(s)	1. PUC6.1: Business as Usual Charging • Monitor Energy Consumption: Track the energy usage of BEBs to identify patterns and inefficiencies. • Utilization Tracking: Monitor the utilization rates of charging stations to understand peak usage times and potential bottlenecks. • Identify Inefficiencies: Analyse the uncoordinated charging process to pinpoint areas where energy and time are being wasted. 2. PUC6.2: Electric Bus Smart Charging • Data Acquisition: Collect data from the DSO, public transport operators, and charging management systems. • Optimize Charging Schedules: Develop algorithms to optimize charging schedules based on SOC, grid demand, and departure schedules. • Cost-Effective Charging: Ensure that charging is performed in a manner that minimizes costs and is friendly to the grid. 3. PUC6.3: Electric Bus Smart Charging with V2G Integration • Bidirectional Energy Flows: Implement V2G technology to allow energy to flow both to and from the grid. • Grid Stabilization: Use electric buses as grid assets to help stabilize the grid during demand fluctuations. 4. PUC6.4 Smart HDV/bus/car park charging • Comprehensive Simulation: Include the total fleet of electric vehicles (HDV/bus/car) in the simulation. • Historical Data Integration: Use the historical data from the SCADA system to help define the scenarios and carry out the simulation. • Smart Charging System: Develop a smart charging system capable of recalculating power and duration for all EVs based on real-time data and requests.

[Narrative of use case](#)

Narrative of use case
Short description

Smart charging of the public transport electric buses and the heavy-duty electric vehicles by introducing optimization techniques. Each primary use case outlines the interactions between key stakeholders, including the bus, charging station, charging management system, DSO, charge point operator (CPO), and public transport operator (PTO). The use case supports the transition to sustainable and grid-friendly heavy duty and public transport electrification

Complete description

The Smart Charging at Depots Use Case will explore how to implement smart charging for electric vehicles, particularly heavy-duty vehicles such as public transport buses and trucks. The aim is to understand how optimization algorithms can be applied to determine the optimal charging schedule for each vehicle.

Currently, depot charging typically occurs in an uncoordinated manner, where battery electric buses charge at maximum power as soon as they return to the depot, continuing until fully charged. This uncoordinated approach is inefficient. Efficiency can be significantly improved by introducing smart charging. Since battery electric buses usually remain in the depot for long periods, their charging process can be managed in a way that benefits the DSO, the CPO, and the PTO.

To achieve the objective of this use case, several actions need to be performed:

1. **Scheduling and Optimization:** Develop and implement a scheduling and optimization algorithm that assigns variable charging currents to different periods of the charging process. This minimizes costs while ensuring that distribution grid limits are not exceeded.
2. **Design of V2G charging infrastructure:** Install a new V2G-capable charging station, provided by Kempower, to evaluate the benefits of flexibility services. This includes both reducing energy withdrawal and enabling controlled energy injection into the DSO grid.
3. **Quantification of Flexibility:** Analyse and quantify the potential flexibility offered by vehicle batteries as distributed energy storage. Based on the results, the DSO may activate flexibility contracts to enhance grid stability and reliability.

This use case will involve a diverse range of applications and stakeholders, including electric vehicle operators, energy providers, charge point operators, and public transport operators. It will evaluate the technical, economic, and regulatory feasibility of smart depot charging, aiming to demonstrate the benefits of optimized bus fleet management and its implications for the medium-voltage grid.

Related primary use case

ID	Name	Description
PUC6.1	Business as Usual Charging	The first PUC covers the traditional, uncoordinated charging process, where buses charge on a first-come, first-served basis without considering grid constraints or optimization. The scope includes monitoring the energy consumption of BEBs, tracking charging station utilization, and identifying inefficiencies in the charging process.
PUC6.2	Electric Bus Smart Charging	The second PUC expands the scope to include smart charging techniques. It involves data acquisition from the DSO, PTOs, and charging management systems etc. The scope includes optimizing charging schedules based on factors such as state of charge, grid demand, and departure schedules. This ensures that charging is performed in a cost-effective and grid-friendly manner.
PUC6.3	Electric Bus Smart Charging with V2G Integration	The third PUC further extends the scope by incorporating bidirectional energy flows through V2G technology. This scenario focuses on utilizing electric buses as grid assets, allowing energy to be withdrawn from or injected into the grid based on demand fluctuations. The scope includes grid stabilization, peak shaving, and increased renewable energy utilization, making BEB charging more sustainable and flexible.

PUC6.4	Smart HDV/bus/car park charging	The fourth PUC considers the total fleet of electric vehicles (HDV/bus/car), which will be simulated and activated based on consumption data from the primary transformer station obtained via the SCADA system. The objective is to design a smart charging system capable of dynamically recalculating charging power levels and durations for all EVs in the depot when required.
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[Related specialized use case](#)

ID	Name	Description
SUC6.1	Southern Europe demo - Milan	In-field validation of smart (and V2G) depot charging for battery electric buses at A2A's site: integration with DSO and charging management systems, schedule optimization versus SOC and departures, and measurement of impacts on costs and medium voltage (MV) grid usage.
SUC6.2	Southern Europe demo - Kranj	Simulation of smart charging for a mixed fleet (HDV/bus/car) using primary substation SCADA time series: testing scheduling algorithms, dynamic recalculation of charging power/duration, and flexibility scenarios toward the distribution grid.

[Key performance indicators \(KPI\)](#)

Key performance indicators			
ID	Name	Description	Reference to mentioned use case objectives
KPI 6.1	Energy Consumption Monitoring	Measure the energy consumption patterns of the battery electric buses	PUC6.1: Business as Usual Charging - Monitor Energy Consumption
KPI 6.2	Charging Optimization	Evaluate the effectiveness of optimized charging.	PUC6.2: Electric Bus Smart Charging
KPI 6.3	V2G Energy Flow	Measure the amount of energy transferred to and from the grid using V2G technology.	PUC6.3: Electric Bus Smart Charging with V2G Integration -
KPI 6.4	Primary Substation Peak Reduction	Measures the percentage reduction of the simulated peak load at the primary transformer when applying smart, dynamically recalculated fleet charging versus an uncoordinated baseline.	PUC6.4 Smart HDV/bus/car park charging

[Use case conditions](#)

Use case conditions
Assumptions
The DSO (Unareti) will provide the point of delivery and allocate the necessary space at the depot for the charging station. The parking area already exists on site.
PUC6.2: CMS receives SOC and departure times with sufficient accuracy to compute feasible schedules. Grid constraints are available for planning
PUC6.3: Vehicles and chargers are technically V2G-ready; DSO allows controlled export at the point of connection.
PUC6.4: Fleet mix, arrival patterns, and charging power limits are known or reasonably estimated.
Prerequisites
PUC6.1: Chargers are installed and log access is enabled.
PUC6.2: CMS is integrated with chargers to allow remote setpoint control.

PUC6.3: A new V2G-capable grid connection is installed and commissioned, including metering, protections, and any required export permissions for bidirectional operation.

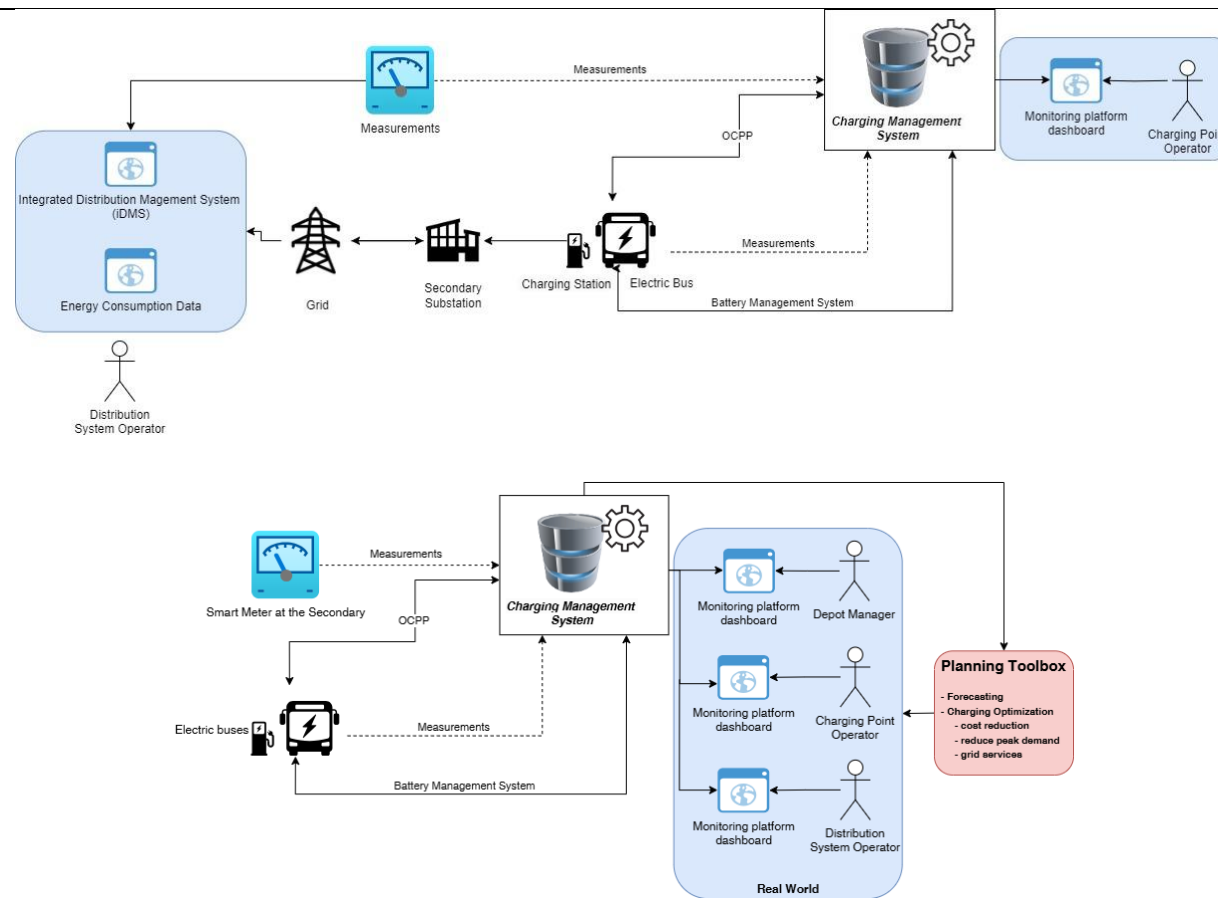
PUC6.4: SCADA time-series imported; fleet models and charger models parameterized; scenario seeds validated.

[Further information to the use case for classification/mapping](#)

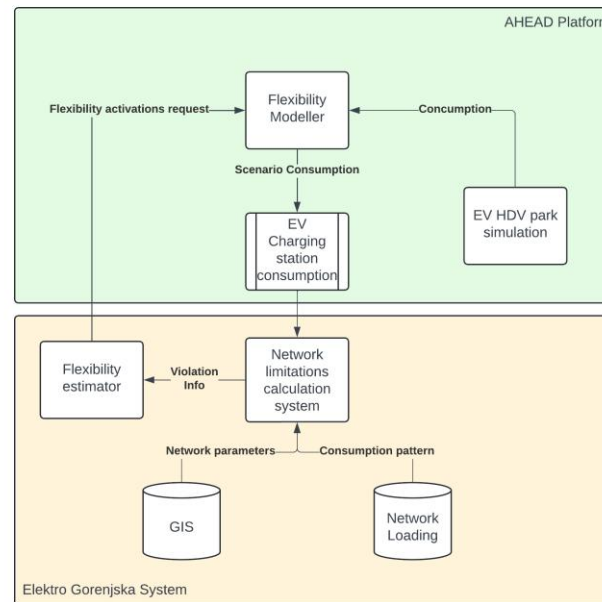
Classification information
Relation to other use cases
There are five use cases related to HLUC6: HLUC1, HLUC4, HLUC5, HLUC7, and HLUC8. All of them involve planning or deploying smart charging in some form; UC1 is also related, as it focuses on the design of new flexibility contracts.
Level of depth
HLUC6 - Developing the Smart Charging at the Depots • PUC6.1: Business as Usual Charging. • PUC6.2: Electric Bus Smart Charging. • PUC6.3: Electric Bus Smart Charging with V2G Integration • PUC6.4 Smart HDV/bus/car park charging • SUC6.1 – Southern Europe demo - Milan • SUC6.2 – Southern Europe demo - Kranj
Prioritisation
High priority for the AHEAD project due to the need to optimize depot charging for bus/HDV fleets, enable flexibility services (including V2G), and reduce grid peak loads. This is both a business and technical priority, responding to new challenges in large-fleet electrification, grid stability, and operational cost management.
Generic, regional or national relation
Regional: implemented within Italy (Milan) and Slovenia (Kranj) regulatory/DSO contexts; concepts are generalizable but dependent on local rules and interconnection codes.
Nature of the use case
Technical/system use case and test use case
Further keywords for classification
Smart Charging, V2G, Optimization Algorithms

Diagram of use case

Diagram(s) of use case
SUC6.1: Southern Europe demo – Milan



SUC6.1: Southern Europe demo – Kranj



Technical details

Actors

Actors			
Grouping		Group description	
Fleet and depot operations		This group includes the organizations that operate, supervise, and use the depot and its services.	
Actor name	Actor type	Actor description	Further information specific to this use case
Charge Point Operator	Role/Human Actor	Operates and maintains the depot charging infrastructure; oversees service delivery and performance.	Receives operational reports/KPIs from CMS; coordinates maintenance and service levels.
Public Transport Operator	Role/Human Actor	Manages bus fleet operations (routes, depots, schedules).	Shares depot schedules and vehicle priorities with CMS for optimized charging.

Actors			
Grouping		Group description	
Grid interface		This group covers external grid stakeholders providing constraints and signals.	
Actor name	Actor type	Actor description	Further information specific to this use case
Distribution System Operator	Role/Human Actor	Ensures grid security; provides limits, events, and (when relevant) flexibility/V2G requests.	Sends grid status/constraints to CMS; may trigger curtailment or V2G events.

Actors			
Grouping		Group description	
Vehicles (fleet entities)		This group includes the vehicles that charge (or discharge) at the depot.	
Actor name	Actor type	Actor description	Further information specific to this use case
BEB	Device	Bus participating in charging (Scenarios 1–3) and V2G where applicable.	Provides arrival/connection events; target SOC/departure; may discharge under V2G.
Vehicle (HDV/BEB/car)	Device	Generic vehicle class used in mixed-fleet operations (Scenario 4).	Includes trucks/HDVs, buses, and cars; each supplies needs/priorities to CMS.

Actors			
Grouping		Group description	
Depot systems and assets		This group includes all systems at the depot that detect, decide, and execute charging.	
Actor name	Actor type	Actor description	Further information specific to this use case
Charging Management System	System Actor	Central brain for planning, scheduling, dispatching, monitoring, and reporting charging sessions.	Ingests SOC, grid constraints, depot priorities; issues setpoints to EVSE; compiles reports/KPIs.
Electric Vehicle Supply Equipment (EVSE)	System Actor	Charging hardware executing start/stop/setpoint commands and metering energy.	Enforces charging profiles from CMS; reports status/energy to CMS.
Battery Management System (BMS)	System Actor	Vehicle-side system reporting SOC/limits and ensuring battery safety.	Provides SOC and constraints to CMS; enforces charge/discharge limits.

Step-by-step analysis of use case

[Overview of scenarios](#)

Scenario conditions

No.	Scenario name	Scenario description	Primary actor	Triggering event	Pre-condition	Post-condition
1	Battery Electric Bus Charging (Business as Usual)	Uncoordinated Charging approach, which might cause load peaks and congestion in the grid.	CMS	The bus entering the charging parking lot	Operational Charging Station	Charging completes without optimization; peak load risk logged.
2	Optimized Battery Electric Bus Charging	The charging management system detects that an electric bus needs to be charged or has entered the facility and needs to decide what would be the optimal time to initialize the charging.	CMS	The bus entering the charging parking lot	Data Acquisition from the DSO, Bus and Public Transport Operator	Optimized charging initiation and completion based on grid conditions and scheduling algorithm output.
3	Battery Electric Bus Charging with V2G	The bus participates in bidirectional energy exchange, charging when the demand is low and discharging when grid demand is high thereby supporting grid stability	CMS	Grid Congestions	V2G-enabled charging infrastructure and grid communication protocols in place.	Energy is either withdrawn (charging) or injected (discharging) based on grid conditions, enhancing system efficiency.
4	Mixed-fleet depot charging	Real-time coordinated charging of a mixed fleet of HDVs, buses, and cars under grid constraints and operational priorities.	CMS	Vehicle arrivals and/or change in DSO constraints	EVSE operational; CMS/CSMS active; SCADA/DSO grid feed available; PTO/CPO schedules shared.	Charging executed within grid limits and depot priorities; KPIs recorded and reported.

Steps-scenarios

Scenario							
Scenario name:		No. 1 – Battery Electric Bus Charging (Business as Usual)					
Step No.	Event	Name of process/ activity	Description of process/ activity	Service	Information producer (actor)	Information receiver (actor)	Information exchanged (IDs)
1.1	Bus arrives at depot	Bus Arrival	Upon return from operation, the bus is plugged into the charging station.	REPORT	BEB	CMS	IE-1.1
1.2	Bus is plugged into the charger	Charging Connection	The bus is connected to the charging station.	EXECUTE	EVSE/BMS	CMS	IE-1.2
1.3	Uncoordinated start	Immediate Charging	The charging session starts without grid coordination or demand management.	EXECUTE	CMS	EVSE	IE-1.3

1.4	Bus reaches the required charge level	Charging Completion	Charging stops when SOC target reached.	CLOSE	EVSE	CMS	IE-1.4
1.5	Report	Post-session reporting	Depot-level charging summary delivered to stakeholders.	REPORT	CMS	DSO, CPO, PTO	IE-1.5

Scenario							
Scenario name:		No. 2 – Battery Electric Bus Charging Optimization					
Step No.	Event	Name of process/activity	Description of process/activity	Service	Information producer (actor)	Information receiver (actor)	Information exchanged (IDs)
2.1	Bus arrives at depot	Bus Arrival	Upon return from operation, the bus is plugged into the charging station.	REPORT	BEB	CMS	IE-1.1
2.2	Bus is plugged into the charger	Charging Connection	The bus is connected to the charging station.	EXECUTE	EVSE/BMS	CMS	IE-1.2
2.3	Data Acquisition	Real-time assessment of the data	CMS gathers SOC, grid limits, departure schedule.	GET	BMS, DSO, PTO	CMS	IE-2.1
2.4	Optimization	Scheduling & Optimization	CMS computes optimal plan based on acquired data to minimize peak loads and grid stress.	EXECUTE	CMS	EVSE	IE-2.2
2.5	Dispatch profile	Smart Charging Command	EVSE receives charging setpoints/profile.	EXECUTE	CMS	EVSE	IE-2.3
2.6	Controlled charging	Plan Execution	Charging begins as per the optimized schedule, preventing grid overload and reducing costs.	EXECUTE	EVSE	CMS	IE-2.4
2.7	Target reached	Charging Completion	The charging session ends when the required SOC is reached, and a notification is sent.	CLOSE	EVSE	CMS	IE-1.4
2.8	Report	Post-session reporting	Depot-level charging summary delivered to stakeholders (energy, durations, curtailments).	REPORT	CMS	DSO, CPO, PTO	IE-2.5

Scenario							
Scenario name:		No. 3 – Battery Electric Bus Charging with V2G					
Step No.	Event	Name of process/activity	Description of process/activity	Service	Information producer (actor)	Information receiver (actor)	Information exchanged (IDs)
3.1	Bus arrives at depot	Bus Arrival	Upon return from operation, the bus is plugged into the charging station.	REPORT	BEB	CMS	IE-1.1
3.2	Bus is plugged into the charger	Charging Connection	The bus is connected to the charging station.	EXECUTE	EVSE/BMS	CMS	IE-1.2

3.3	Data Acquisition	Real-time assessment of the data	CMS gathers SOC, grid limits, departure schedule.	GET	BMS, DSO, PTO	CMS	IE-2.1
3.4	Flex request	V2G Activation Request	If the grid requires support, the DSO sends a request to initiate power injection from the bus battery.	CREATE	DSO	CMS	IE-3.1
3.5	Bidirectional control	V2G Power Flow Control	CMS commands EVSE for charge/discharge. The BEB is controlled for providing peak shaving or frequency regulation.	EXECUTE	CMS	EVSE	IE-3.2
3.6	Session end	V2G Completion	V2G stops (limits or objectives met).	CLOSE	EVSE/BMS	CMS	IE-3.3
3.7	Report & KPIs	Post-session reporting	Depot-level summary to stakeholders (energy, durations, curtailments).	REPORT	CMS	DSO, CPO, PTO	IE-3.4

Scenario							
Scenario name:		No. 4 – Mixed-fleet depot charging					
Step No.	Event	Name of process/activity	Description of process/activity	Service	Information producer (actor)	Information receiver (actor)	Information exchanged (IDs)
4.1	Vehicles arrive at depot	Vehicle arrival notification	Each vehicle checks in at the depot and indicates charging need.	REPORT	Vehicle (HDV/BEB/car)	CMS	IE-1.1
4.2	Connect to charger	Connection registration	Vehicle connects to an available EVSE; connection is validated.	CREATE	EVSE/BMS	CMS	IE-1.2
4.3	Gather inputs	Data acquisition	CMS collects grid load and forecasts, battery SOC, depot schedule and priorities.	GET	DSO, PTO, Vehicles	CMS	IE-2.1; IE-4.1
4.4	Decide priorities	Fleet prioritization & allocation	CMS ranks vehicles (departure times, SOC, route priority) and allocates chargers/power.	EXECUTE	CMS	CMS	IE-2.2
4.5	Dispatch profiles	Charging profile dispatch	Optimized per-vehicle current/power profiles are sent to EVSEs.	EXECUTE	CMS	EVSE	IE-2.3
4.6	Start charging	Controlled charging start	EVSEs start charging per assigned profiles.	EXECUTE	EVSE	Vehicles	IE-2.4
4.8	Constraint event	Grid constraint notification (optional)	If DSO signals a constraint, CMS reduces/pauses selected sessions.	CHANGE	DSO	CMS/EVSE	IE-3.1; IE-2.3
4.9	Session completion	Charging completion	When target SOC/departure time is reached, session is closed and logged.	CLOSE	EVSE	CMS	IE-1.4
4.10	Report & KPIs	Post-session reporting	Depot-level summary to stakeholders (energy, durations, curtailments).	REPORT	CMS	DSO, CPO, PTO	IE-4.2

Information exchanged

<i>Information exchanged</i>		
<i>Information exchanged, ID</i>	<i>Name of information</i>	<i>Description of information exchanged</i>
IE-1.1	Arrival Notification	Message from the bus indicating arrival at the depot and readiness for charging (includes vehicle ID, timestamp, current SOC).
IE-1.2	Connection Registration Data	Confirmation that the vehicle is physically connected to the EVSE and the session can be initialized (EVSE ID, connector ID, handshake status).
IE-1.3	Uncoordinated Charging Start	Event logged when charging begins without optimization or grid coordination (start timestamp, initial power/current setpoint, EVSE session ID).
IE-1.4	Charging Completion Notification	Notification that charging has ended because the target SOC was reached (end timestamp, final SOC, energy delivered, session summary).
IE-1.5	Depot Charging Summary (Scenario 1)	Post-session report (energy delivered, duration, KPIs) for stakeholders.
IE-2.1	Optimization Input Dataset	Aggregated inputs for planning: current SOC, grid constraints/limits, departure schedule and priorities, time window.
IE-2.2	Optimized Charging Plan	CMS-generated optimized plan (per-vehicle allocation, power trajectories, start/stop windows, constraints compliance).
IE-2.3	Charging Profile Command	Setpoints/profiles issued to EVSE (target current/power over time, ramp limits, control mode).
IE-2.4	Charging Execution Status	Live execution feedback from EVSE (applied power/current, interim energy delivered, exceptions).
IE-2.5	Depot Charging Summary (Scenario 2)	Post-session report (energy delivered, duration, peak reduction, curtailments, KPIs) for stakeholders.
IE-3.1	V2G Activation Request	Formal request from DSO specifying service type (discharge/charge), power/energy, start window, duration/constraints.
IE-3.2	V2G Setpoint Command	CMS to EVSE command with bidirectional setpoints (target power/energy, ramps, max/min SOC, stop criteria).
IE-3.3	V2G Session Completion	Closure notice including delivered/absorbed energy, final SOC, timestamps, reasons for stop.
IE-3.4	V2G Session Report	Aggregated report/KPI for stakeholders (peak shaving achieved, response time, curtailments, compliance).
IE-4.1	Grid Load & Forecast (SCADA)	Real-time grid load and short-term forecast from the DSO's SCADA system (e.g., feeder/transformer active/reactive power, voltage; frequency where available).
IE-4.2	Mixed-Fleet Charging Report & KPIs	End-of-scenario report summarizing per-vehicle sessions and fleet-level KPIs during mixed-fleet depot operations.

Common terms and definitions

<i>Common terms and definitions</i>	
<i>Term</i>	<i>Definition</i>
Battery Electric Bus (BEB)	A fully electric bus powered solely by batteries; participates in depot charging and, where enabled, V2G services.
BMS	Battery management systems
CMS	Charging management system
CPO	Charge point operator
EV	Electric vehicle
Electric Vehicle Supply Equipment (EVSE)	Charging hardware that executes start/stop/setpoint commands and meters delivered/absorbed energy.
HDV	Heavy-duty vehicle

HLUC	High-level use case
Mixed-Fleet Depot	Depot operating multiple vehicle classes (HDV, BEB, cars) under a unified charging strategy.
MV	Medium voltage
PTO	Public transport operator
PUC	Primary use case
SCADA (Supervisory Control and Data Acquisition)	DSO system providing real-time measurements and forecasts (e.g., load, voltage) used by CMS for decisions.
SOC	State of charge
SUC	Specialized use case
V2G	Vehicle-to-grid

II.VII HLUC7 – Smart charging in highways

Description of the use case

Name of the use case

Use case identification		
ID	Area/Domain(s)/Zone(s)	Name of use case
HLUC7	Area: energy system Domain: distribution system Zones: Operation, station, field	Smart charging in highways

Version management

Version management			
Version No.	Date	Name of author(s)	Changes
0.0	05.09.24	Marzio Barresi (POLIMI)	First template provided
0.1	04.03.25	Zoltan Mark Pinter (DTU)	First draft of HLUC7
0.2	02.06.25	Zoltan Mark Pinter (DTU)	Second draft of HLUC7
0.3	22.10.25	Marzio Barresi (POLIMI)	Final draft version of HLUC7

Scope and objectives of use case

Scope and objectives of use case	
Scope	The High-Level Use Case (HLUC) focuses on implementing smart charging in highways. The Location 1 will test the coordination of a hybrid battery energy storage system and renewable energy sources (BESS+RESs) buffered fast charging station. Here, the sensitivity of utilization rate to charging prices will be tested. Additionally, SYSLAB facilities will be used to demonstrate low voltage (LV) grid challenges, as well as solutions from flexibility services to the distribution system operator (DSO) (emulated by SYSLAB) and transmission system operator (TSO). Three Primary Use Cases (PUCs) will be derived from this HLUC. • PUC7.1 – Management of a Hybrid (BESS+RES) Buffered Fast Charging Station • PUC7.2 – User Response to Dynamics Charging Price Approaches • PUC7.3 – LV Grid Planning Challenges and Solutions • PUC7.4 – Test Flexibility Services for DSOs and TSOs One Specialized Use Case (SUCs) will be derived according to demo site: • SUC7.1 – Nordic Europe demo – Fast charging demo
Objective(s)	1. Develop a multi-objective framework to optimize energy buffering

- | | |
|--|---|
| | <ol style="list-style-type: none"> 2. Identify user needs and price sensitivity 3. Highlighting main grid planning challenges and proposing cost-effective compensations 4. Integrating flexibility services into the existing optimization platform |
|--|---|

Narrative of use case

Narrative of use case	
Short description	
Location 1 will test a full package coordination of a hybrid (BESS+RES) buffered fast charging station. Here, we will test the correlation of charging prices methodologies with utilization rate. Additionally, leveraging the SYSLAB facilities, we will demonstrate LV grid challenges and solutions coming from flexibility services to the DSO and TSO.	
Complete description	
The demonstration exercises an end-to-end highway fast-charging hub buffered by hybrid on-site resources, where a battery energy storage system and local renewable generation (PV) enable 150 kW fast charging despite a constrained grid connection of roughly 43 kW. The BESS and PV are coordinated to meet power demand, respect grid limits, and preserve service quality. A multi-objective energy management system (EMS) manages grid imports, BESS charge/discharge, and PV utilization to secure available power at the charger while minimizing curtailment, maximizing self-consumption and self-sufficiency, and exploiting time-shifting. Fast-charging operations are paired with alternative pricing approaches to measure their effects on utilization, waiting time, and user satisfaction, allowing the project to quantify price elasticity without compromising quality of service. Using SYSLAB, the project observes and emulates low-voltage network conditions (e.g., congestion, transformer loading, voltage drop, and THD) under realistic fast-charging profiles, then tests cost-effective mitigations such as BESS set-point policies, PV smoothing, ramp-rate limits, and charger power-factor control. Whenever operating conditions allow, the EMS also exposes flexibility to the DSO/TSO, reducing imports or providing upward/downward reserve, via coordinated BESS–charger control.	

Related primary use case

ID	Name	Description
PUC7.1	Management of a Hybrid (BESS+RES) Buffered Fast Charging Station	Developing a multi-objective framework to optimize energy buffering. Outlining revenues, costs, and constraints for optimization. Highlighting the sensitivity and constraints of hardware. Identify recommendable periods for charging and discharging the battery system.
PUC7.2	User Response to Dynamics Charging Price Approaches	Identifying KPIs for maximizing user experience. Determining the sensitivity of the user to the prices, either fixed or variable.
PUC7.3	LV Grid Planning Challenges and Solutions	Determining possible challenges such as congestion, transformer overload, voltage drop or high total harmonic distortion (THD) levels. Identifying potential compensation methods and investigating whether they are worth the investment.
PUC7.4	Test Flexibility Services for DSOs and TSOs	Finding mandatory flexibility services and adequate flexibility markets for the size of the application. Identifying optimal times and constraints to participate in the market. Testing feasibility of market participation.

Related specialized use case

ID	Name	Description
SUC7.1	Nordic Europe demo – Fast charging demo	Location 1 at Risø campus is located in the Danish countryside and gives the possibility to all users to utilize the newly installed fast-charging infrastructure provided by KEMPOWER (operated commercially by SPIRII). In addition, due to reduced grid capacity (43 kW availability) the location will utilize the combination of a BESS from Pixii (325kWh/150kW) and local photovoltaic (PV) production to deliver 150 kW of fast charging. This combination resembles future charging hubs and reduces the grid capacity requirements.

Key performance indicators (KPI)

Key performance indicators			
ID	Name	Description	Reference to mentioned use case objectives
PUC 7.1			
KPI7.1	Profit	The revenues from fast-charging and flexibility services cover the application and organizational expenses, creating some profit. This can be used for reinvestment, or to increase the stakeholder base. Unit: DKK	Objective 1
KPI7.2	Self-sufficiency	The more power for electric vehicle (EV)-charging originates from RESs, the less money is lost on paying for power capacity of the lines and difference between buying and selling electricity prices. Unit: %	Objective 1
KPI7.3	Curtailment avoidance	Curtailment either means that the fast-charging application cannot fulfill the maximum power request, or that the ROI of the RES increases. Therefore, the amount of curtailment period should be minimized. The amount of curtailed energy is not investigated, assuming that the system is properly sized. Unit: time/day (to be minimized)	Objective 1
KPI7.4	Autonomy	The more effective rule-base can be set up from hindsight, the more robust the algorithms become to stochastics, and independent of measurements. The values of reduced optimization problems can be compared to the results of KPI 7.1.1 Unit: DKK	Objective 1
PUC 7.2			
KPI7.5	Price	The price should be fair and competitive, as long as it does not significantly reduce demand. Unit: DKK	Objective 2
KPI 7.6	User satisfaction	The user satisfaction can be measured by surveys, and apart from weighing the negative of KPI 7.2.1, as well as KPI 7.2.3, KPI 7.2.4 and KPI 7.2., a survey may find further user sensitivities. Unit: %	Objective 2
KPI 7.7	Waiting time avoidance	Waiting for charging or queueing requires passive time of the user and causes frustrating user experience. Therefore, waiting time should be minimized. Unit: time/day (to be minimized)	Objective 2
KPI 7.8	Curtailment avoidance	System constraints can prevent the fast-charging application fulfilling the maximum power request. Therefore, curtailment should be minimized. Unit: time/day (to be minimized)	Objective 2
PUC 7.3			

KPI7.9	Self-consumption	The more RES is used locally, the less congestion and transformer overload. Unit: %	Objective 3
KPI7.10	Self-sufficiency	Identical to KPI 7.1.2. The more power for EV-charging originates from RESs, the less chance of congestion and transformer overload. Unit: %	Objective 3
KPI7.11	Voltage drop compensation	The impedance of the lines causes voltage drops, which causes inefficient use of equipment, power factor issues and reduced available power. Therefore, voltage drop should be minimized. Unit: V	Objective 3
KPI7.12	THD reduction	Power electronics equipment works inefficiently, potentially overload, and degrades faster at higher THD levels, as well as power quality can decrease. Therefore, THD should be minimized. Unit: %	Objective 3
PUC 7.4			
KPI7.13	Income	The amount of money acquired from flexibility services should be maximal. Unit: DKK	Objective 4
KPI7.14	Service time independence	The time spent on providing electricity for fast-charging and flexibility services should be as separated as possible, to increase the robustness of the system against stochastics. Unit: time/day (to be minimized)	Objective 4

Use case conditions

<i>Use case conditions</i>	
Assumptions	
PUC7.1	- A sufficient number of charging infrastructure and users regularly use the demo locations.
PUC7.2	- The data collected from the interacting users can be generalized to the EV owner community. - The users do not have alternative motivations to charge at the fast-charging location, apart from their satisfaction with the charging experience. - The users do not appreciate increased waiting time/charging time at the charger.
PUC7.3	- A sufficient number of charging infrastructure and users regularly use the demo locations
PUC7.4	- The system has sufficient power/energy capacities to provide flexibility services.
Prerequisites	
PUC7.1	- The system is controlled and monitored and the events are logged. - The system is sufficiently sized to provide a reasonable self-sufficiency and self-consumption.
PUC7.2	- The users are provided with the necessary information to realize the existence of the charger, and to locate it. This can be by road signs, or via the Spiirii application / Google Maps.
PUC7.4	

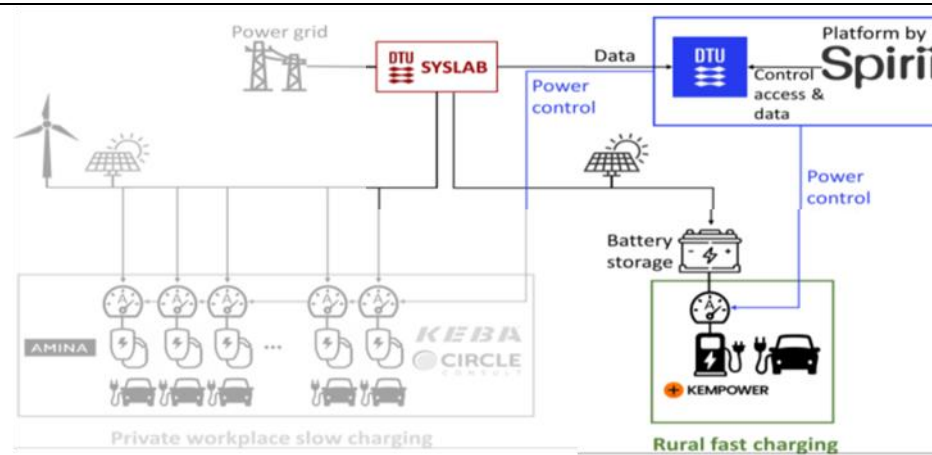
- The system complies with relevant regulations such as Teknisk Forskrift 3.3.1 (TF3.3.1).

[Further information to the use case for classification/mapping](#)

Classification information
Relation to other use cases
The following HLUCs related to HLUC7: HLUC1, HLUC2, HLUC5, HLUC9, HLUC10, HLUC11, HLUC12
Level of depth
HLUC 7 - Smart charging in highways • PUC7.1 – Management of a Hybrid (BESS+RES) Buffered Fast Charging Station • PUC7.2 – User Response to Dynamics Charging Price Approaches • PUC7.3 – LV Grid Planning Challenges and solutions • PUC7.4 – Test Flexibility Services for DSOs and TSOs • SUC7.1 – Nordic Europe demo – Fast charging demo
Prioritisation
High priority for AHEAD since this use case has regulatory, technical and business relevance.
Generic, regional or national relation
Regulatory and business perspective can be affected by national/regional environment.
Further keywords for classification
Flexibility services, smart charging, user experience, congestion management

[Diagram of use case](#)

Diagram(s) of use case



Technical details

Actors

Actors			
Grouping		Group description	
Site assets and resources		This group contains on-site physical systems that produce, store, and deliver energy for fast charging.	
Actor name	Actor type	Actor description	Further information specific to this use case
PV System	System Actor	On-site photovoltaic generation provides local energy and forecasts to EMS.	PV System installed at SYSLAB,
BESS	System Actor	On-site storage used for buffering, peak shaving, and flexibility.	BESS installed at SYSLAB.
Smart Charging Station	System Actor	DC fast charger delivering power to EVs per EMS setpoints.	Fast charger supplied by Kempower.

Actors	
Grouping	Group description

Site control and operations		This group includes the software and operational entities that authorize sessions, optimize power flows, and dispatch setpoints.	
Actor name	Actor type	Actor description	Further information specific to this use case
Parking Lot EMS	System Actor	Optimizes charging and buffering; computes/dispatches setpoints; enforces grid limits.	Consumes PV/DSO/TSO/BESS inputs; issues EVSE and BESS setpoints.
CPO	Business Actor	Authorizes sessions, applies tariffs, and manages payments/customer access.	Spiirii operates the fast-charger front end (communications and payment terminals).

Actors			
Grouping		Group description	
Grid and system stakeholder		This group includes the software and operational entities that authorize sessions, optimize power flows, and dispatch setpoints.	
Actor name	Actor type	Actor description	Further information specific to this use case
DSO	Role/Human actor	Provides local grid constraints/events; validates grid-friendly operation.	SYSLAB emulates the local DSO.
TSO	Role/Human actor	Publishes system alerts/constraints; may request flexibility.	Energinet connects to SYSLAB and balances supply with demand.

Actors			
Grouping		Group description	
Users		This group represents end customers who initiate charging sessions and provide usage preferences.	
Actor name	Actor type	Actor description	Further information specific to this use case
Electric Vehicle Owner/User	Human actor	Driver using the fast-charging hub; provides preferences and receives session status.	Mix of EV types and user preferences.

References

References						
No.	References type	Reference	Status	Impact on use case	Originator/ organization	Link
R7.1	Regulation	TF3.3.1	Valid from 1 January 2023	Limiting application and requiring flexibility service	Energinet	https://energinet.dk/media/nlpp4svx/19-12961-1-teknisk-forskrift-331-for-elektriske-energilageranlaeg-rev-3.pdf

Step-by-step analysis of use case

Overview of scenarios

Scenario conditions						
No.	Scenario name	Scenario description	Primary actor	Triggering event	Pre-condition	Post-condition
1	Optimal Energy Management	EV arrives; CPO delivers the requested energy optimizing power sharing.	CPO/Parking Lot EMS	EV user requests charging.	Aggregator platform, real-time data feeds from the grid, user acceptance.	EV charged, user costs, and comfort.

Steps-scenarios

Scenario							
Scenario name:		No. 1 - Normal scenario					
Step No.	Event	Name of process/activity	Description of process/activity	Service	Information producer (actor)	Information receiver (actor)	Information exchanged (IDs)
1.1	EV arrival at the parking lot	EV arrives at charging station	The EV reaches the parking facility, where the driver parks in an available charging spot,	REPORT	Electric Vehicle Owner/User	Parking Lot EMS	IE-1.1
1.2	Connection detected	Register EV connection	The charging infrastructure establishes a link with the electric vehicle and sets it up for use.	CREATE	Smart Charging Station	Parking Lot EMS	IE-1.2
1.3	Session authorization	User/contract check	The CPO authorizes the charging session.	EXECUTE	CPO	Parking Lot EMS/Smart Charging Station	IE-1.3
1.4	Site inputs collected	RES & grid data acquisition	The PV System provides real-time/forecast PV output; BESS provides state/availability; the DSO provides grid limits; the TSO provides system alerts/constraints (if any).	GET	PV system, BESS, DSO, TSO	Parking Lot EMS	IE-1.4; IE-1.5; IE-1.6; IE-1.7
1.5	Schedule computed	Charging setpoint calculation	EMS computes setpoints that respect grid limits and use local resources.	EXECUTE	Parking Lot EMS	Parking Lot EMS	IE-1.8
1.6	Charging starts	Initiate charging	The Parking Lot EMS initiates the charging of the EV in accordance with a calculated schedule that prioritizes the utilization of PV system and BESS. Additionally, the charging process is	EXECUTE	Parking Lot EMS	Smart Charging Station	IE-1.9

			designed to operate within the constraints of the grid's power supply.				
1.7	Charging progresses	Adjust charging schedule	EMS monitors PV output, grid constraints, and BESS state; it adjusts EV and BESS setpoints as conditions evolve.	CHANGE	Parking Lot EMS	Smart Charging Station	IE-1.10,
1.8	Charging complete	End charging session	Charging sessions end when the EV reaches its desired state of charge or the user-defined end time is met.	CLOSE	Smart Charging Station	Parking Lot EMS/ Electric Vehicle Owner/User	IE-1.11

Information exchanged

<i>Information exchanged</i>			
<i>Information exchanged, ID</i>	<i>Name of information</i>	<i>Description of information exchanged</i>	
IE-1.1	Charging Request and Preferences	EV/driver request to charge, including desired SOC, departure time, and any user constraints.	
IE-1.2	Connection Registration Data	Confirmation that the EV is physically connected and ready.	
IE-1.3	Session Authorization	Authorization decision from the CPO (approved/denied), with related token/contract reference and tariff context if applicable.	
IE-1.4	PV Output and Forecast	Real-time PV power and short-term forecast made available to EMS for planning.	
IE-1.5	BESS state and availability	BESS status and parameters.	
IE-1.6	DSO Grid Limits and Events	Current grid constraints/notifications from the DSO (feeder/transformer limits, curtailment windows, voltage constraints).	
IE-1.7	TSO System Alerts/Constraints	System-level advisories that may affect charging (e.g., reserve events, system alerts), when applicable.	
IE-1.8	Computed Charging Setpoints	EMS-calculated per-session setpoints/profile (target power/current over time, ramps, start/stop windows).	
IE-1.9	Charging Start Command	EMS instruction to the charger to start the session under the computed profile.	
IE-1.10	Real-time Adjustment Command	EMS adjustments to the running session (increase/decrease/pause/resume) based on changing PV/BESS/grid/user conditions.	
IE-1.11	Charging Completion Notification	End-of-session summary (stop reason, final SOC, energy delivered, timestamps) sent to EMS and/or user.	

Common terms and definitions

<i>Common terms and definitions</i>	
<i>Term</i>	<i>Definition</i>
BESS	Battery energy storage system
CPO	Charge point operator

DSO	Distribution system operator
EMS	Energy management system
EV	Electric vehicle
HLUC	High-level use case
LV	Low voltage
PUC	Primary use case
PV	Photovoltaic
RES	Renewable energy sources
SOC	State of charge
SUC	Specialized use case
SYSLAB	DTU's experimental facility used here to emulate the DSO grid and test control strategies.
THD	Total harmonic distortion
TSO	Transmission system operator

II.VIII HLUC8 – Smart charging in port areas

Description of the use case

Name of the use case

Use case identification		
ID	Area/Domain(s)/Zone(s)	Name of use case
HLUC8	Area: energy system Domain: Distribution system Zones: ports	Smart charging in port areas

Version management

Version management			
Version No.	Date	Name of author(s)	Changes
0.0	05.09.24	Marzio Barresi (POLIMI)	First template provided
0.1	02.06.25	Lucas Pereira (IST-ID), Gustavo Miranda (IST-ID), Cindy Guzman (INESC-ID)	First draft of HLUC8
0.2	22.10.25	Marzio Barresi (POLIMI)	Final draft version of HLUC8

Scope and objectives of use case

Scope and objectives of use case	
Scope	This High-Level Use Case (HLUC) focus on demonstrating vessel charging in port areas, with a focus on small vessels dedicated to maritime-touristic activities. The demonstration will be on the scope of the Western Europe demo site, more specifically in the city of Funchal, Madeira. The initiative integrates three primary use cases (PUCs): 1) <u>PUC8.1 – Uncoordinated Charging Impact Analysis</u>. Scope: <i>Quantify and assess the consequences of a complete electrification of the vessels in the port without implementing charging coordination. The focus will be on assessing strain on the local grid, and identifying potential issues in the distribution systems, e.g., voltage and frequency outside the accepted boundaries.</i> 2) <u>PUC8.2 – Electric and Hybrid Vessel Smart Charging</u>. Scope: <i>Optimizing the charging schedule of the vessels using predictive and control algorithms, while maintaining a reliable grid connection and minimizing the costs with electricity. Moreover, the impact on the business activities must be minimal. It shouldn't be necessary to make large deviations to the scheduled trips.</i> 3) <u>PUC8.3 – Grid-Aware Electric and Hybrid Vessel Smart Charting with Flexibility Signals from the distribution system operator (DSO)</u>. Scope: <i>Builds upon PUC8.2 by integrating external grid signals and enabling flexibility services for the DSO. Like in the previous PUC, the impact on business activities must be minimal.</i>

	The HLUC8 will be developed in Madeira, resulting in three Specialized Use Cases (SUCs): 1) SUC8.1 – Western Europe Demo – Funchal 2) SUC8.2 – Western Europe Demo – Funchal 3) SUC8.3 – Western Europe Demo – Funchal
Objective(s)	1) <u>PUC8.1 – Uncoordinated Charging Impact Analysis</u>. Objective: To develop a hardware-in-the-loop simulator (using the vessel charger developed in HLUC4), to enable the simulation of different levels of electrification of the maritime-touristic activities. To conduct different simulations and assess the impacts of uncoordinated vessel charging, using KPIs such as the minimum and maximum aggregated demand, or the total time that the peak demand is above or below a specific threshold. 2) <u>PUC8.2 – Electric and Hybrid Vessel Smart Charging</u>. Objective: To extend the simulator to include the availability of stationary storage devices. To simulate different smart charging alternatives and benchmark against the baseline results obtained in PUC8.1. 3) <u>PUC8.3 – Grid-Aware Electric and Hybrid Vessel Smart Charging with Flexibility Signals from the DSO</u>. Scope: To extend the simulator to include the simulation of flexibility requests from the DSO. To simulate different smart-charging alternatives that can accommodate flexibility requests from the DSO. To benchmark against the results obtained in PUC8.2.

Narrative of use case

Narrative of use case	
Short description	This use cases explore the potential of smart charging solutions within port areas, focusing first on how they can be used to the seamless integration of electric vessels in maritime-touristic activities; and second, on how smart charging solutions can provide flexibility services to DSOs. Considering the objectives and solutions tested in this use case, there are synergies with the remaining use cases: HLUC4 (novel charging technologies), and HLUC11 (activation of flexibility services by DSOs).
Complete description	This use case focuses on the development and utilization of a hardware-in-the-loop (HIL) simulator to analyse the effects of uncoordinated and smart vessel charging, integrating various levels of electrification and flexibility mechanisms. The HIL simulator will use a vessel charger developed in UC4 to create a realistic simulation environment for maritime-touristic electrification. It will conduct simulations to assess the impact of the uncoordinated charging by key performance indicators such as minimum and maximum aggregated demand and total duration that peak demand exceeds or remains below a predefined threshold. Then an enhancement of the HIL simulator will be conducted through the Integration of Flexibility Requests from the DSO. Moreover, a development and assessment of smart-charging alternatives will be implemented to accommodate DSO flexibility requests while optimizing vessel charging operations. The investigation of this technology's functionality will be structured based on the <i>birdsEView</i> aggregator vessel smart charging framework that, in an initial step, integrates real-world data collection, digital twin simulation, renewable energy management, and demand response to optimize electric vessel charging at ports. Smart meters and EV chargers communicate via open charge point protocol (OCPP), sending real-time measurements to the <i>birdsEView</i> Aggregator. The port simulator generates trip-based simulations using historical data, modelling vessel and charger behaviour, while the port assets initially include vessel models and charger behaviour analysis. As the framework evolves, battery energy storage systems (BESSs) and solar PV are introduced into the port assets, enhancing renewable energy integration. A planning toolbox is incorporated, enabling forecasting, charging optimization, cost reduction, self-consumption, and peak demand reduction to improve energy efficiency and sustainability. Given the relatively predictable operational patterns of maritime-touristic activities, including scheduled routes and docking periods, the planning tool will also exploit vessel timetables and charging availability windows to improve charging coordination and energy management. These insights, made available through the <i>birdsEView</i> dashboard and apps, empower port authorities and vessel companies to make data-driven decisions.

Further enhancements include the introduction of a city chargers' module, which connects with public electric vehicle supply equipments (EVSEs) to coordinate private and public charging. The Planning Toolbox expands to include grid services, optimizing energy distribution. Additionally, the birdsEView flexibility sandbox enables demand response, allowing interaction with DSOs. By combining real-time monitoring, predictive simulations, and advanced energy planning, the system enhances port electrification, improves operational efficiency, and facilitates seamless grid integration.

The anticipated outcomes of this system incorporate a validated HIL simulator, capable of assessing the impact of vessel electrification under different scenarios. It provides insights into the effects of uncoordinated vessel charging on the electrical grid, helping stakeholders understand potential challenges. To enhance grid stability, the system includes a framework for integrating stationary storage solutions, leveraging BESS. Additionally, it offers a comprehensive evaluation of flexibility mechanisms and their role in demand-side management, ensuring efficient energy distribution. The Planning Toolbox and birdsEView flexibility sandbox further support recommendations for optimal smart-charging strategies, balancing vessel charging needs with DSO flexibility requirements.

[Related primary use case](#)

ID	Name	Description
PUC8.1	Uncoordinated Charging Impact Analysis	Through simulation with will be possible to establish a baseline scenario for different levels of vessel electrification (until 100%), without any smart charging in place.
PUC8.2	Electric and Hybrid Vessel Smart Charging	Introduces smart charging solutions that consider only the needs of the port and business, optimizing energy use to reduce costs and ensure operational reliability (e.g., lowering the bill and making sure that the tourism operations are not compromised).
PUC8.3	Grid-Aware Smart Charging with Flexibility from DSO	Builds on PUC8.2 by incorporating external signals from the DSO, enabling the port to provide dynamic grid support (e.g., responding to DSO requirements for flexibility)

[Related specialized use case](#)

ID	Name	Description
SUC8.1	Uncoordinated Charging Impact Analysis – Western Europe Demo – Funchal	use case is specific to the maritime-touristic activities taking place in the Port of Funchal. At present, only one hybrid vessel is in operation; therefore, it is necessary to develop a simulation platform capable of modelling both vessels and their trips. For this case study, different levels of electrification will be considered, up to a scenario in which 100% of the vessels in the marina are electric or hybrid. Simulations will be carried out assuming uncoordinated charging, i.e. when, upon docking, each vessel starts charging until the battery is full or another trip begins. The objective is to establish a baseline for energy costs and grid constraints that would arise if no smart charging strategies were implemented.
SUC8.2	Electric and Hybrid Vessel Smart Charging – Western Europe Demo – Funchal	This use case extends SUC8.1 by introducing smart charging algorithms as well as the presence of onsite renewable energy sources (RESs) and BESS. The simulation will follow the same levels of electrification defined SUC8.1. The smart charging will focus on specific objectives, including costs reduction, peak demand management, and maximizing the levels of RES self-consumption. A direct comparison will be made against the results obtained for SUC8.1.
SUC8.3	Grid-Aware Smart Charging with Flexibility from DSO –	This use case extends SUC8.2 by introducing flexibility requests from the DSO. During this use case, explicit (also known as incentive-based) demand response will be considered. Different levels of electrification will be simulated as well as different levels

	Western Europe Demo – Funchal	of response-rates from the demand-side (e.g., by defining different willingness levels to participate in the DR actions for each vessel). In the end, a direct comparison will be made against the results obtained for SUCs 8.1 and 8.2.
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Key performance indicators (KPI)

Key performance indicators			
ID	Name	Description	Reference to mentioned use case objectives
SUC8.1			
KPI8.1	Total cost of operation	The total cost of operation in terms of Euros per kWh considering different levels of vessel electrification	Objective 1
SUC8.2			
KPI8.2	Reduction in cost of operation	The total reduction in the cost of operation with respect to KPI8.1a	Objective 2
KPI8.3	Reduction in Peak Energy Demand	Percentage decrease in peak energy demand due to optimized smart charging strategies.	Objective 2
KPI8.4	Self-Consumption Rates	Increase in self-consumption rates for the different levels of electrification and PV-BESS combinations	Objective 2
SUC8.3			
KPI8.5	Flexibility Services Tested	Number of flexibility services tested during the search for the one which fits the use case goals	Objective 3
KPI8.6	Reduction in cost of operation	The total reduction in the cost of operation with respect to KPIs 8.1a and 8.2a	Objective 3
KPI8.7	Reduction in Peak Energy Demand	Percentage decrease in peak energy demand due to optimized smart charging strategies.	Objective 3
KPI8.8	Self-Consumption Rates	Increase in self-consumption rates for the different levels of electrification and PV-BESS combinations	Objective 3

Use case conditions

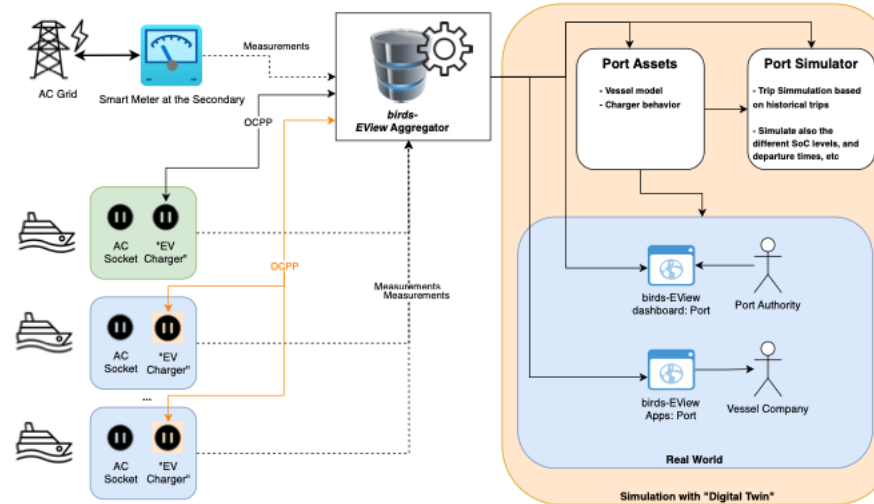
Use case conditions	
Assumptions	
SUC8.1	
Each vessel operator is operating in a single-rate tariff, and it is assumed that the connection point, i.e., secondary substation, does not impose a power limit.	
SUC8.2	
Each vessel operator is subject to a peak power contract and can have a different energy tariff in place, e.g., Time of Use. All the electricity is supplied by the same secondary substation, which has an upper limit that must be respected to avoid blackouts.	
SUC8.3	
The assumptions of SUC8.2 plus the fact that the DSO can submit flexibility requests, and the vessel operators are able to accommodate such requests.	
Prerequisites	
- An electric connection is available in the proximity of the vessel docking areas. - A hybrid or fully electric vessel is available in the marina where the developed connector will be deployed.	

[Further information to the use case for classification/mapping](#)

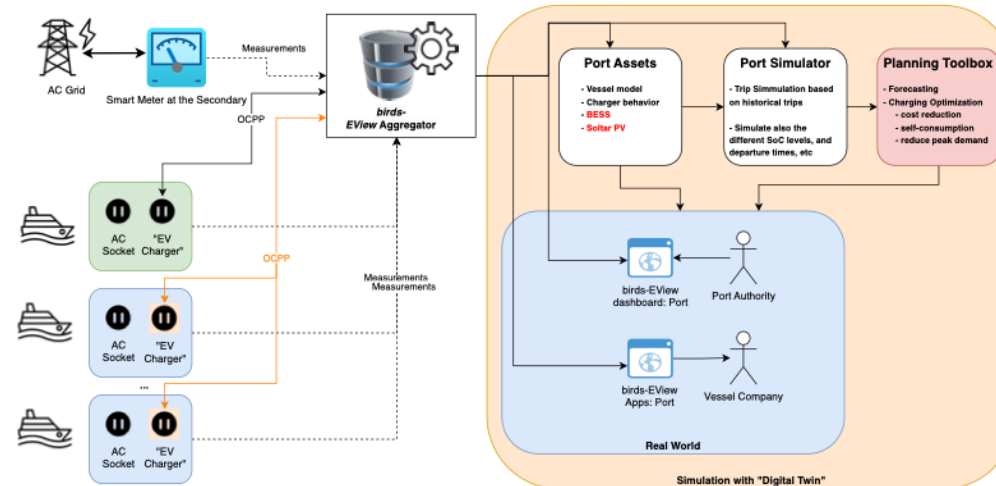
Classification information
Relation to other use cases
Includes PUC4.2 (technical feasibility and value proposition of vessel charging)
Level of depth
HLUC8 - Smart charging in port areas - PUC8.1 – Uncoordinated Charging Impact Analysis - PUC8.2 – Electric and Hybrid Vessel Smart Charging - PUC8.3 – Grid-Aware Smart Charging with Flexibility from DSO Each SUC builds on the previous one. - SUC8.1 – Uncoordinated Charging Impact Analysis – Western Europe Demo – Funchal: aims to assess what will happen if electrification occurs without proper counter measures on the grid side and no smart charging is in place - SUC8.2 – Electric and Hybrid Vessel Smart Charging – Western Europe Demo – Funchal: aims to assess counter measures put in place by the port managers, focusing on inclusion of distributed energy resources and smart-charging - SUC8.3 – Grid-Aware Smart Charging with Flexibility from DSO – Western Europe Demo – Funchal: expands the counter measures to the DSO side, which will be able to indirectly affect the load demand due to vessel charging
Prioritisation
High priority due to the relevance of studying vessel charging scenarios, even if resorting to simulation at this stage.
Generic, regional or national relation
SUC8.2 and SUC8.3 are subject to regional and national regulation in place. This is particularly relevant for SUC8.3, which implies the existence of a flexibility market.
Nature of the use case
Simulation-based test use case.
Further keywords for classification
Maritime-touristic activities, smart-charging of small vessels, full electric and hybrid vessels, hardware in the loop, real-time simulation, smart charging

[Diagram of use case](#)

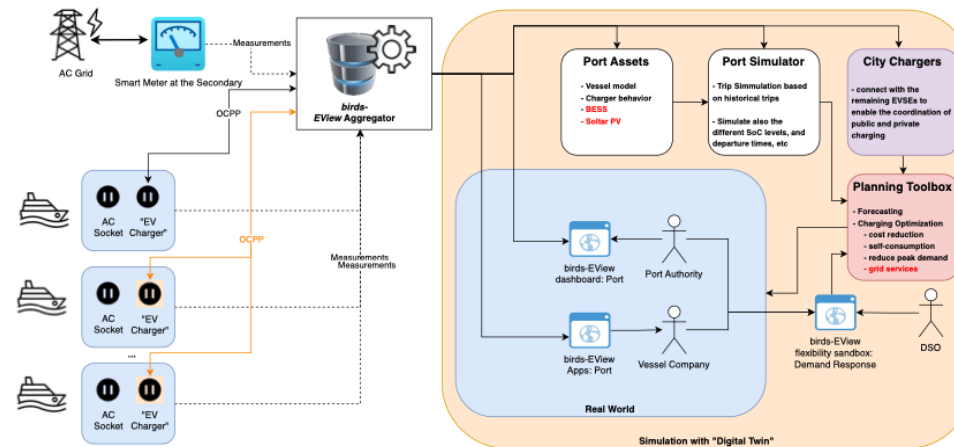
Diagram(s) of use case
SUC8.1: Uncoordinated Charging Impact Analysis – Western Europe Demo – Funchal



SUC8.2: Electric and Hybrid Vessel Smart Charging – Western Europe Demo



SUC8.3: Grid-Aware Smart Charging with Flexibility from DSO – Western Europe Demo – Funchal



Technical details

Actors

Actors			
Grouping		Group description	
Impact of Uncoordinated Charging		This group of actors is involved in assessing the potential consequences of an uncoordinated approach to vessel electrification. (PUC8.1)	
Actor name	Actor type	Actor description	Further information specific to this use case
Port Operator	Human Actor	Manages all the port infrastructure, regarding all the vessels, their docking and charging facilities.	It has the role of observing how an uncoordinated charging approach affects port operations and its infrastructure.
Vessel/Vessel Operator	Human Actor	Operate the electric/ hybrid vessel that needs the charging.	Whenever the operators dock the vessels, in order to charge them, a peak demand period is noticeable.
Grid Operator (DSO)	Human Operator	Ensures grid stability and manages its distribution throw the entire network.	Monitors uncoordinated charging's impact on grid constraints.
Charging Simulation Tool	System Actor	Software that models and simulates the charging behaviour of the vessels.	Simulates vessels with different electrification, taking the KPIs as reference.

Actors			
Grouping		Group description	
Smart Charging Implementation		This group of actors is responsible for testing and deploying smart charging solutions that optimize energy consumption and vessel operations. (PUC8.2)	
Actor name	Actor type	Actor description	Further information specific to this use case
Port Operator	Human Actor	Manages all the port infrastructure, regarding all the vessels, their docking and charging facilities.	It has the role of observing how an uncoordinated charging approach affects port operations and its infrastructure.
Vessel/Vessel Operator	Human Actor	Operate the electric/ hybrid vessel that needs the charging.	Whenever the operators dock the vessels, in order to charge them, a peak demand period is noticeable.
Grid Operator (DSO)	Human Operator	Ensures grid stability and manages its distribution throw the entire network.	Monitors uncoordinated charging's impact on grid constraints.
Charging Simulation Tool	System Actor	Software that models and simulates the charging behaviour of the vessels.	Simulates vessels with different electrification, taking the KPIs as reference.
Smart Charging Optimization Platform	System Actor	' <i>Charging Simulation Tool</i> ' complementary software which optimizes charging schedules based on predictive smart charging models.	Computes and implements optimal charging schedules.
RES Manager	System Actor	Oversees integration of renewable energy sources into the charging system.	Ensures RES availability is considered in smart charging schedules.
BESS Operator	Human Actor	Manages energy storage systems to balance demand.	Use the battery to buffer port demand peaks, provide contingency support for vessel charging, and enable flexibility services without violating battery constraints.

Actors			
Grouping		Group description	
Grid-Aware Smart Charging with Flexibility		This group of actors plays a crucial role in integrating smart charging solutions with DSO flexibility services. (PUC8.3)	
Actor name	Actor type	Actor description	Further information specific to this use case
Port Operator	Human Actor	Manages all the port infrastructure, regarding all the vessels, their docking and charging facilities.	It has the role of observing how an uncoordinated charging approach affects port operations and its infrastructure.
Vessel/Vessel Operator	Human Actor	Operate the electric/ hybrid vessel that needs the charging.	Whenever the operators dock the vessels, in order to charge them, a peak demand period is noticeable.
Grid Operator (DSO)	Human Operator	Ensures grid stability and manages its distribution throw the entire network.	Monitors uncoordinated charging's impact on grid constraints.
Charging Simulation Tool	System Actor	Software that models and simulates the charging behaviour of the vessels.	Simulates vessels with different electrification, taking the KPIs as reference.
Smart Charging Optimization Platform	System Actor	' <i>Charging Simulation Tool</i> ' complementary software which optimizes charging schedules based on predictive smart charging models.	Computes and implements optimal charging schedules.
RES Manager	System Actor	Oversees integration of renewable energy sources into the charging system.	Ensures RES availability is considered in smart charging schedules.

BESS Operator	Human Actor	Manages energy storage systems to balance demand.	Use the battery to buffer port demand peaks, provide contingency support for vessel charging, and enable flexibility services without violating battery constraints.
Flexibility Services Provider	System Actor	Manages real-time flexibility requests from the DSO and dispatches them to relevant actors.	The real-time flexibility requests will have direct impact in different actors' actions, which will lead to a direct impact on the final results gathered from the simulation.

Step-by-step analysis of use case

Overview of scenarios

Scenario conditions						
No	Scenario name	Scenario description	Primary actor	Triggering event	Pre-condition	Post-condition
1	Uncoordinated Vessel Charging	The vessel arrives to the port, docks and immediately starts charging without any coordination with the grid, potentially overloading the grid. No predictive optimization or schedule is done.	Vessel operators	Vessel docks and connects to charger.	The charging station is operational and there is a charging demand by the vessel.	The vessel charges without considering the grid conditions, potentially leading to peak demands and an increased energy cost.
2	Optimized Smart Charging	The vessel arrives to the port, docks and using predictive algorithms determines the best charging strategy, either for the vessels and the grid. The optimization will incorporate energy from RES and BESS when available.	Vessel operators	Vessel requests to start charging.	The vessel is connected to a smart charging and the system has access to the grid data, as well as the vessel charging schedules	The vessel is charged according to an optimized schedule that balances the grid load and vessel's operational needs.
3	Smart Charging with Flexibility	The vessel arrives to the port, docks and whenever charging, its system integrates price signals from the DSO, adjusting the vessel charging based on the market prices and simultaneously considering the grid load and the vessel operational needs.	Vessel operators	The DSO submits a flexibility request	The vessel is connected to a smart charging and the system has access grid data, vessel charging schedules as well as the signals from the DSO.	The vessel charging process adapts dynamically to support grid stability while minimizing its costs, always maintaining the vessel's operational needs.

Steps-scenarios

Scenario							
Scenario name:		No. 1 – Uncoordinated Vessel Charging					
Step No.	Event	Name of process/activity	Description of process/activity	Service	Information producer (actor)	Information receiver (actor)	Information exchanged (IDs)

1.1	Simulation setup	Scenario initialization	Simulation Tool loads scenario inputs (arrival time, vessel demand, grid capacity) and starts the run.	CREATE	Charging Simulation Tool	-	IE-1.1
1.2	Vessel arrives at port	Vessel Arrival Notification	The vessel enters the port and communicates its arrival.	REPORT	Vessel / Vessel Operator	Port Operator	IE-1.2
1.3	Vessel docks	Docking Process	The vessel places itself into the dock and prepares for its connection with the charging infrastructure.	EXECUTE	Vessel / Vessel Operator	Port Operator	IE-1.3
1.4	Vessel requests charging	Charging Request Submission	The vessel requests charging based on its battery status and energy needs.	CREATE	Vessel / Vessel Operator	Port Operator	IE-1.4
1.5	Charging station acknowledges request	Charging Request Confirmation	The charging station acknowledges the vessel's request and checks for available power.	REPORT	Port Operator	Vessel / Vessel Operator	IE-1.5
1.6	Charging connection established	Charging Setup	The charging station establishes a connection with the vessel and prepares to deliver energy.	EXECUTE	Port Operator	Vessel / Vessel Operator	IE-1.6
1.7	Charging station receives request	Immediate Charging Start	The charging station starts delivering energy without considering grid conditions.	EXECUTE	Port Operator	Vessel / Vessel Operator	IE-1.7
1.8	Charging progress	Proceeds an Uncoordinated Charging	The vessel charges at its maximum possible rate, potentially causing grid overload.	EXECUTE	Port Operator	Vessel / Vessel Operator	IE-1.8
1.9	Charging completes	Charging Session Ends	The vessel stops charging once its battery reaches full capacity.	EXECUTE	Port Operator	Vessel / Vessel Operator	IE-1.9
1.10	Report	Post-session reporting	Session report on status/energy draw; peak demand may be observed.	REPORT	Charging Simulation Tool	Grid Operator (DSO); Port Operator	IE-1.10

Scenario							
Scenario name:		No. 2 – Optimized Smart Charging					
Step No.	Event	Name of process/activity	Description of process/activity	Service	Information producer (actor)	Information receiver (actor)	Information exchanged (IDs)
2.1	Simulation setup	Scenario initialization	Simulation Tool loads inputs (arrivals, grid capacity,	CREATE	Charging Simulation Tool	-	IE-2.1

			RES/BESS profiles) and starts run.				
2.2	Vessel arrives at port	Vessel Arrival Notification	The vessel enters the port and communicates its arrival.	REPORT	Vessel / Vessel Operator	Port Operator	IE-1.2
2.3	Vessel docks	Docking Process	The vessel places itself into the dock and prepares for its connection with the charging infrastructure.	EXECUTE	Vessel / Vessel Operator	Port Operator	IE-1.3
2.4	Vessel requests charging	Charging Request Submission	The vessel requests charging based on its battery status and energy needs.	CREATE	Vessel / Vessel Operator	Port Operator	IE-1.4
2.5	Charging station acknowledges request	Charging Request Confirmation	The charging station acknowledges the vessel's request and checks for available power.	REPORT	Port Operator	Vessel / Vessel Operator	IE-1.5
2.6	Charging connection established	Charging Setup	The charging station establishes a connection with the vessel and prepares to deliver energy.	EXECUTE	Port Operator	Vessel / Vessel Operator	IE-1.6
2.7	Inputs to optimizer	Site and grid data acquisition	RES Manager sends RES availability/forecast; BESS Operator sends BESS state/limits; DSO sends grid constraints/events.	GET	RES Manager; BESS Operator; Grid Operator (DSO)	Smart Charging Optimization Platform	IE-2.2
2.8	Charging station receives request	Charging Optimization Request	The charging station requests an optimized schedule from the smart charging system.	GET	Port Operator	Smart Charging Optimization Platform	IE-2.3
2.9	Smart charging system calculates optimal schedule	Charging Schedule Optimization	The smart charging system considers factors such as the grid constraints, possibly RES and BESS to determine the best charging plan.	CREATE	Smart Charging Optimization Platform	Port Operator	IE-2.4
2.10	Optimized charging starts	Smart Charging Execution	The charging station delivers adjusted power, based on the optimized schedule.	EXECUTE	Port Operator	Vessel / Vessel Operator	IE-2.5
2.11	Charging progresses	Power Adjustments	The optimized schedule computed by the charging simulation tool adjusts the power delivered to the vessel and the use of RES/BESS based on grid conditions.	CHANGE	Smart Charging Optimization Platform; Charging Simulation Tool	Port Operator; RES manager; BESS Operator; Grid Operator (DSO)	IE-2.6

2.10	Charging completes	Optimized Charging Completion	The vessel finishes its charging according to the optimized plan.	EXECUTE	Port Operator	Vessel / Vessel Operator	IE-2.7
2.11	Report	Post-session reporting	Depot-level summary for the simulated run (energy, durations, RES/BESS usage, curtailments, KPIs) is generated and shared.	REPORT	Charging Simulation Tool	Port Operator; RES manager; BESS Operator; Grid Operator (DSO))	IE-2.8

Scenario							
Scenario name:		No. 3 – Smart Charging with Flexibility					
Step No.	Event	Name of process/activity	Description of process/activity	Service	Information producer (actor)	Information receiver (actor)	Information exchanged (IDs)
3.1	Simulation setup	Scenario initialization	Simulation Tool loads inputs (arrivals, grid capacity, RES/BESS profiles) and starts run.	CREATE	Charging Simulation Tool	-	IE-2.1
3.2	Vessel arrives at port	Vessel Arrival Notification	The vessel enters the port and communicates its arrival.	REPORT	Vessel / Vessel Operator	Port Operator	IE-1.2
3.3	Vessel docks	Docking Process	The vessel places itself into the dock and prepares for its connection with the charging infrastructure.	EXECUTE	Vessel / Vessel Operator	Port Operator	IE-1.3
3.4	Vessel requests charging	Charging Request Submission	The vessel requests charging based on its battery status and energy needs.	CREATE	Vessel / Vessel Operator	Port Operator	IE-1.4
3.5	Charging station acknowledges request	Charging Request Confirmation	The charging station acknowledges the vessel's request and checks for available power.	REPORT	Port Operator	Vessel / Vessel Operator	IE-1.5
3.6	Charging connection established	Charging Setup	The charging station establishes a connection with the vessel and prepares to deliver energy.	EXECUTE	Port Operator	Vessel / Vessel Operator	IE-1.6
3.7	Inputs to optimizer	Site and grid data acquisition	RES Manager sends RES availability/forecast; BESS Operator sends BESS state/limits; DSO sends grid constraints/events.	GET	RES Manager; BESS Operator; Grid Operator (DSO)	Smart Charging Optimization Platform	IE-2.2

3.8	Charging station receives request	Charging Optimization Request	The charging station requests an optimized schedule from the smart charging system.	GET	Port Operator	Smart Charging Optimization Platform	IE-3.1
3.9	Smart charging system calculates optimal schedule	Charging Schedule Optimization	The smart charging system considers factors such as grid constraints, RES and BESS status, and flexibility signals to determine the optimal charging plan.	CREATE	Smart Charging Optimization Platform	Port Operator	IE-3.2
3.10	Flexibility signal	Flexibility request	Flexibility Services Provider relays a real-time flexibility request from DSO to the optimizer.	CHANGE	Flexibility Services Provider; Grid Operator (DSO)	Smart Charging Optimization Platform	IE-3.3
3.11	Smart charging system processes flexibility signals	Integration of Flexibility Market Data into the optimal schedule	The smart charging system receives flexibility requests and price signals from the DSO and updates the optimal schedule dynamically.	CHANGE	Smart Charging Optimization Platform	Port Operator	IE-3.4
3.12	Optimized charging starts	Smart Charging Execution	The charging station delivers an adjusted power, based on the optimized schedule.	EXECUTE	Port Operator	Vessel / Vessel Operator	IE-3.5
3.13	Charging progresses	Power Adjustments	The optimized schedule computed by the charging simulation tool adjusts the power delivered to the vessel and the use of RES/BESS based on grid conditions and flexibility request.	CHANGE	Smart Charging Optimization Platform; Charging Simulation Tool	Port Operator; RES manager; BESS Operator; Grid Operator (DSO); Flexibility Services Provider	IE-3.6
3.14	Charging completes	Optimized Charging Completion	The vessel finishes its charging according to the optimized plan and flexibility requests.	EXECUTE	Port Operator	Vessel / Vessel Operator	IE-3.7
3.15	Report	Post-session reporting	Depot-level summary for the simulated run including flexibility activations (requested vs delivered), impacts on charging, costs, and KPIs.	REPORT	Charging Simulation Tool	Port Operator; RES manager; BESS Operator; Grid Operator (DSO))	IE-3.8

Information exchanged

Information exchanged		
Information exchanged, ID	Name of information	Description of information exchanged

IE-1.1	Scenario Initialization Parameters	Simulation inputs (arrival times, demand profiles, grid capacity, time step, random seeds).
IE-1.2	Arrival Notification	Notification sent by the vessel when it enters the port, enabling the port operator to prepare for docking.
IE-1.3	Docking Confirmation	Confirmation that the vessel has successfully docked and is ready for charging process.
IE-1.4	Charging Request Details	Information on the vessel's energy needs and battery status, mandatory to initiate the charging process.
IE-1.5	Charging Availability Status	Acknowledgment from the charging station regarding the availability of power for the vessel's request.
IE-1.6	Charging Setup Confirmation	Confirmation that the charging station is ready and the connection with the vessel is established.
IE-1.7	Charging Start Confirmation	Confirmation from the charging station that energy delivery has begun without grid condition analysis.
IE-1.8	Uncoordinated Charging Status	Ongoing status (instantaneous power, cumulative energy, duration) during uncoordinated charging.
IE-1.9	Charging Completion Notification	Notification that the vessel's battery is fully charged (or up to the established value requested by the vessel operator) and the process is complete.
IE-1.10	Energy Consumption Report (Scenario 1)	Data on energy usage and its various information from the energy exchange during the charging process.
IE-2.1	Scenario Initialization Parameters (Scenario 2 and 3)	Simulation inputs (arrival times, demand profiles, grid capacity, time step, random seeds, RES/BESS profiles).
IE-2.2	Site and Grid Input Dataset	RES/BESS data, DSO constraints/events
IE-2.3	Optimized Charging Schedule Request	Request for an optimized charging schedule, considering possible grid constraints.
IE-2.4	Optimized Charging Schedule	Schedule developed by the smart charging system to minimize grid impact and maximize efficiency.
IE-2.5	Charging Start/Dispatch Command	Instruction from the Port Operator to the charger to start (or re-start) the session under the optimized schedule.
IE-2.6	Real-Time Grid Adjustments	Adjustments to be made on the power delivery in response to grid conditions and charging progress, according to the smart charging schedule.
IE-2.7	Charging Completion Notification (Scenario 2)	Notification that the vessel's charging is complete according to the optimized plan.
IE-2.8	Session Run Report and KPIs (Scenario 2)	Consolidated post-run report for the simulated operation shared with all stakeholders.
IE-3.1	Optimized Charging Schedule Request	Request for an optimized charging schedule, considering flexibility signals and the possible grid constraints.
IE-3.2	Optimized Charging Schedule (flexibility)	Schedule developed by the smart charging system, builds on the grid-optimized schedule by incorporating DSO signals to provide market flexibility while maintaining minimized grid impact and maximized efficiency.
IE-3.3	Flexibility Request Message	Real-time request forwarded from the DSO (via the Flexibility Services Provider) to the optimizer, including requested service (up/down), power/energy, start time window, duration, and constraints.
IE-3.4	Flexibility-Adjusted Optimized Schedule	Updated charging schedule produced by the optimizer that incorporates the flexibility request while respecting grid constraints, RES/BESS limits, and vessel needs.

IE-3.5	Flexibility-Adjusted Start Command	Instruction from the Port Operator to initiate or re-initiate charging under the flex-adjusted schedule.
IE-3.6	Real-Time Adjustments and Status Under Flexibility Services	Streaming setpoint changes (increase/decrease/pause/resume) during flexibility activation; includes applied power, RES/BESS dispatch and any exceptions.
IE-3.7	Charging Completion Notification (Scenario 3)	Notification that the vessel's charging is complete according to the optimized/flexibility plan.
IE-3.8	Session Run Report and KPIs (Scenario 3)	Consolidated post-run report for the simulated operation shared with all stakeholders.

Common terms and definitions

Common terms and definitions	
Term	Definition
BESS	Battery energy storage system
DSO	Distribution system operator
EVSE	Electric vehicle supply equipment
Hardware-in-the-Loop Simulator	A simulation tool that integrates physical hardware (e.g., vessel charger developed in UC4) with virtual models (e.g., electric vessels) to test and analyse real-world scenarios.
HLUC	High-level use case
OCPP	Open charge point protocol
PUC	Primary use case
RES	Renewable energy source
Smart Charging	A charging approach that optimizes energy consumption by dynamically adjusting charging power based on grid conditions and pricing.
SOC	State of charge
SUC	Specialized use case
Time-of-Use (TOU)	Electricity tariff with rates that vary by time period (e.g., peak/off-peak).
Uncoordinated Charging	A charging approach where vessels charge immediately once docking, without consideration for grid constraints or optimization, potentially leading to peak loads.
Vessel Electrification	The process of replacing the traditional fuel-powered vessels with electric alternatives. This process includes all the necessary charging infrastructure.

II.IX HLUC9 – Coordinated charging via charge point operators

Description of the use case

Name of the use case

Use case identification		
ID	Area/Domain(s)/Zone(s)	Name of use case
HLUC9	Area: energy system; Domains: distribution system, customers; Zones: market, operation, field	Coordinated charging via charge point operators

Version management

Version management			
Version No.	Date	Name of author(s)	Changes
0.0	05.09.24	Marzio Barresi (POLIMI)	First template provided
0.1	11.10.24	Lenart Ribnikar (EG)	First draft of HLUC9
0.2	03.02.25	Blaž Dobravec (EG)	Second draft of HLUC9
0.3	18.03.25	Blaž Dobravec (EG)	Third draft of HLUC9
0.4	29.04.25	Blaž Dobravec (EG)	Fourth draft of HLUC9
0.5	28.05.25	Blaž Dobravec (EG)	Fifth draft of HLUC9
0.6	22.10.25	Marzio Barresi (POLIMI)	Final draft version of HLUC9

Scope and objectives of use case

Scope and objectives of use case	
Scope	The High-Level Use Case (HLUC) will test the user-engagement in charging strategies informed by artificial intelligence (AI) data. It will also demonstrate coordinated charger aggregation concepts and test the flexibility services for grid operators. Two Primary Use Cases (PUCs) will be derived from this HLUC. • PUC9.1 – Real-time Charging Optimization • PUC9.2 – Grid Flexibility Service Request Three Specialized Use Cases (SUCs) will be derived according to demo site: ▪ SUC9.1 – Nordic Europe demo ▪ SUC9.2 – Western Europe demo ▪ SUC9.3 – Southern Europe demo
Objective(s)	Objectives of HLUC9 are:

- | | |
|--|--|
| | <ol style="list-style-type: none"> 1) Evaluating user-engagement in AI-informed charging strategies. 2) Testing coordinated charging by charge point operators (CPOs). 3) Testing flexibility services for distribution system operators (DSOs) and transmission system operators (TSOs). |
|--|--|

[Narrative of use case](#)

<i>Narrative of use case</i>	
Short description	
The Coordinated Charging via CPOs use case focuses on testing user engagement in AI-driven charging strategies and demonstrating the coordination of CPOs. It aims to evaluate how users interact with charging strategies informed by artificial intelligence and to explore how various charging vendors can work together to offer flexible services. Additionally, the use case will assess the benefits of these flexibility services for DSOs and TSOs. This use case aims to improve the coordination between electric vehicle (EV) charging networks and grid operators, ensuring a more efficient and flexible energy system.	
Complete description	
The Coordinated Charging via CPOs use case explores how EV users engage with AI-driven charging strategies. The goal is to understand how AI can optimize charging times and patterns, balancing individual needs with grid requirements. Imagine a user arriving at an EV charging station—here, instead of charging immediately at full power, AI analyses real-time data, including energy prices, grid load, and the user's travel plans, to recommend an optimal charging schedule. Users can follow these suggestions, gaining potential benefits like lower costs or contributing to a greener energy mix by charging when renewable energy is abundant. The demonstrator will also assess user preferences and acceptance of different charging strategies, including trade-offs between charging cost, convenience, and environmental impact. In addition to the AI-driven user experience, the use case also involves coordinating multiple charging providers (CPOs) on a shared platform, showcasing how various vendors' charging stations can work together seamlessly. This aggregation ensures users can access consistent charging experience across different locations and operators. The system also connects with the grid operators—both DSOs and TSOs—to offer flexibility services. For example, during peak demand, the grid might signal a need to reduce charging speed or postpone charging. In return, users or charging operators may be compensated for offering this flexibility. To achieve this coordination and flexibility, the use case will rely on distribution-grid models integrated into the power-system simulation environment, including detailed representations of low-voltage networks where available. This integration enables precise simulation and near-real-time assessment of grid conditions so that the AI-driven charging strategies remain aligned with network capacity and stability needs. By coupling grid models with the simulation framework, we can evaluate alternative charging scenarios, forecast grid impacts, and optimize charging schedules while maintaining balance and flexibility, particularly during peak periods. This approach is critical for accommodating growing EV demand without compromising reliability or efficiency. The project will demonstrate these features in a lab environment. The goal is to ensure that EV charging infrastructure can scale up without stressing the grid, while also providing a smooth and efficient charging experience for users. Ultimately, this could lead to a more resilient, sustainable, and user-friendly EV ecosystem.	

[Related primary use case](#)

<i>ID</i>	<i>Name</i>	<i>Description</i>
PUC9.1	Real-time Charging Optimization	Focuses on real-time data processing to provide charging recommendations based on grid and user data.

PUC9.2	Grid Flexibility Service Request	Details the communication and execution of flexibility requests from grid operators to adjust charging behaviours.
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[Related specialized use case](#)

ID	Name
SUC9.1	Nordic Europe demo
SUC9.2	Western Europe demo
SUC9.3	Southern Europe demo

[Key performance indicators \(KPI\)](#)

Key performance indicators			
ID	Name	Description	Reference to mentioned use case objectives
KPI9.1	User Adoption Rate	Proportion of EV users who follow AI-recommended charging schedules.	Objective 1
KPI9.2	Response Time to Flexibility Requests	Average time taken for the CPOs to adjust charging in response to a DSO/TSO flexibility request.	Objective 2, Objective 3
KPI9.3	Peak Load Reduction	Percentage reduction in grid peak load due to coordinated charging strategies.	Objective 3

[Use case conditions](#)

Use case conditions
Assumptions
All participating charging stations are equipped with communication modules capable of real-time data exchange.
Grid operators (DSOs/TSOs) have integrated systems to communicate real-time flexibility requests.
Prerequisites
Successful integration of the DSO's grid data into the analysis framework is required.
Real-time interfaces must exist between AI system, CPOs, and grid operators.
User consent to receive AI recommendations and engage with flexible charging must be obtained.
Functional interfaces must exist between the CPO systems, AI system, and grid operator systems.

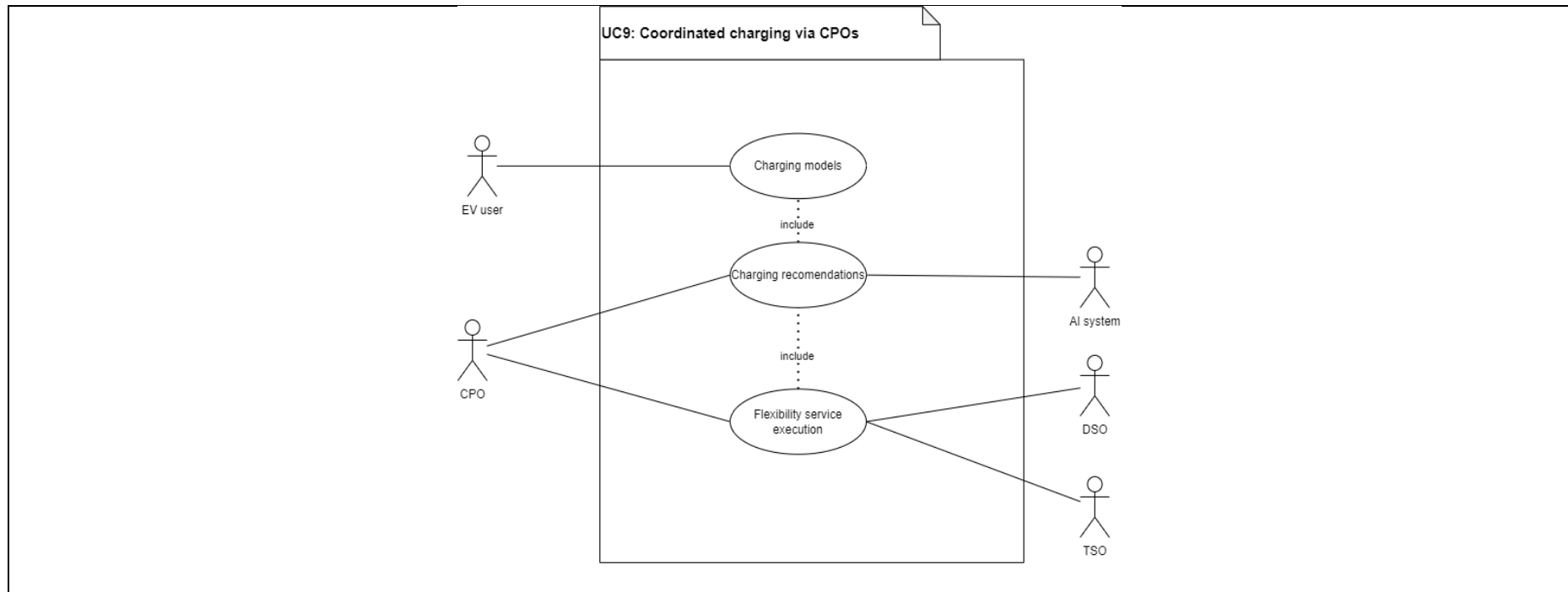
[Further information to the use case for classification/mapping](#)

Classification information
Relation to other use cases
HLUC1: New DR and flexibility contracts: HLUC9 supports flexibility contracts by demonstrating user engagement in AI-driven charging strategies. The flexibility contract has to reflect the entire consortium of vendors and not only a single vendor.
HLUC10: Coordinated charging in a VPP setup: HLUC9 helps test coordinated charging through coordinated charging, similar to a Virtual Power Plant (VPP) setup.
HLUC11: Activation of flexibility services by DSOs: HLUC9 demonstrates user engagement in flexibility services for DSOs, facilitating real-time grid adjustments. Which can be directly linked to the coordination of the CPOs.

<i>Level of depth</i>
HLUC9 - Coordinated charging via CPOs • PUC9.1 – Real-time Charging Optimization • PUC9.2 – Grid Flexibility Service Request ▪ SUC9.1 – Nordic Europe demo ▪ SUC9.2 – Western Europe demo ▪ SUC9.3 – Southern Europe demo
<i>Prioritisation</i>
The use case is optional, since EV flexibility can be procured directly from individual vendors. Nevertheless, this approach is cumbersome; consequently, there is a clear business need to enhance efficiency and ease of use for service users.
<i>Generic, regional or national relation</i>
This use case is designed in a way that can be applied across multiple regions and countries. While specific regulations or grid configurations might differ, the general approach of combining multiple CPOs for a more robust flexibility offerings is a common concept.
<i>Nature of the use case</i>
Technical/system use case: The use case focuses on technical aspects, such as the integration of AI-driven charging strategies, multi-vendor aggregation, and real-time grid flexibility management. Business use case: It also includes business aspects, as it seeks to improve the overall charging experience for users while reducing operational costs for grid operators (DSOs/TSOs) and charging providers (CPOs).
<i>Further keywords for classification</i>
Smart charging, electric vehicles, charging infrastructure, AI-driven optimization, multi-vendor integration, grid flexibility, demand response, smart grid, energy optimization, sustainable transportation, flexibility services, EV user engagement.

Diagram of use case

<i>Diagram(s) of use case</i>



Technical details

Actors

Actors			
Grouping		Group description	
Smart charging ecosystem		Entities that request, provide, coordinate, and supervise EV charging and flexibility services.	
Actor name	Actor type	Actor description	Further information specific to this use case
EV users	Business Actor	Individuals or businesses using electric vehicles. They interact with charging stations to charge their vehicles and provide data on charging behaviours and preferences.	May accept or override AI-recommended schedules.
CPO	Business Actor	The actor responsible for managing and maintaining the charging infrastructure.	Implements adjustments from AI system and fulfils DSO/TSO requests received via the platform.
AI system	Logical Actor	A computational system that processes real-time data to optimize charging strategies. It provides recommendations for	Interfaces with CPOs and the multi-vendor platform; logs KPIs.

		optimal EV charging and calculates flexibility based on DSO/TSO requirements.	
DSO	Business Actor	The business entity responsible for managing the low-voltage distribution grid.	The DSO gains insights into grid flexibility and issues requests for flexibility services, working with the AI system to balance grid loads.
TSO	Business Actor	The actor responsible for the high-voltage transmission grid.	The TSO coordinates with the DSO and CPOs to ensure grid stability by managing broader grid flexibility needs, especially during peak periods.
Multi-vendor Platform	System Actor	Interoperability layer that discovers stations across multiple CPOs, aggregates status/tariffs/constraints, and dispatches sessions to the selected CPO.	Provides a single interface to the AI system and users; supports vendor selection and unified monitoring across networks.

References

References						
No.	References type	Reference	Status	Impact on use case	Originator/organization	Link
R9.1	Industry Standard	IEC 61850 (Communication networks and systems in substations)	In use	Ensures secure and reliable communication protocols	IEC	https://www.iec.ch/homepage

Step-by-step analysis of use case

Overview of scenarios

Scenario conditions						
No.	Scenario name	Scenario description	Primary actor	Triggering event	Pre-condition	Post-condition
1	AI-Driven Charging Recommendation	EV user plugs in; charging station sends data to AI system; AI returns an optimal charging schedule based on current data.	EV User	Arrival at charging station	User registered; station online; AI system has up-to-date grid and pricing data	Charging schedule displayed and confirmed; charging begins as per recommendation.
2	Grid Flexibility Request	DSO/TSO issues a flexibility request due to a surge in grid load; the system adapts charging sessions accordingly.	DSO/TSO	Detection of high grid load or prediction.	All connected charging stations are responsive; AI system actively monitoring grid conditions	Charging rates adjusted; grid load mitigated.
3	Multi-Vendor Aggregation	A charging session is initiated using a multi-vendor network; the system selects the optimal vendor based on availability.	CPO	User request for charging	Charging stations from multiple vendors are integrated on the platform	User receives charging service from the vendor with optimal performance.

Steps-scenarios

Scenario							
Scenario name:		No. 1 - AI-Driven Charging Recommendation					
Step No.	Event	Name of process/activity	Description of process/activity	Service	Information producer (actor)	Information receiver (actor)	Information exchanged (IDs)
1.1	Plug-in	Session initialization	EV is connected; the CPO captures user/vehicle/state of charge (SOC) data.	EXECUTE	EV User	CPO	IE-1.1
1.2	Context fetch	Grid and price snapshot	The AI pulls current grid conditions and prices.	GET	DSO/TSO	AI system	IE-1.2
1.3	Optimize	Schedule computation	The AI computes optimal start/stop and power profile.	EXECUTE	AI system	CPO/EV user	IE-1.3
1.4	Confirm	User consent	The user accepts or edits the proposal.	REPORT	EV user	CPO/AI system	IE-1.4
1.5	Dispatch	Setpoint delivery	The CPO applies the AI's charging instructions.	EXECUTE	CPO	EV user	IE-1.5
1.6	Monitor	Session monitoring	Telemetry and status flow to CPO/AI	REPORT	CPO	AI system	IE-1.6
1.7	Complete	Session closeout	Close on target reached or user stop.	CLOSE	CPO	AI system/EV user	IE-1.7

Scenario							
Scenario name:		No. 2 - Grid Flexibility Request					
Step No.	Event	Name of process/activity	Description of process/activity	Service	Information producer (actor)	Information receiver (actor)	Information exchanged (IDs)
2.1	Grid stress	Flexibility need assessment	DSO/TSO detects a risk of limit exceedance.	REPORT	DSO/TSO	-	-
2.2	Issue request	Flexibility request	Formal request for load reduction/shift is sent.	CREATE	DSO/TSO	AI system	IE-2.1
2.3	Re-optimize	Schedule update	The AI recalculates affected sessions.	EXECUTE	AI system	CPO	IE-2.2
2.4	Dispatch	Adjustment instructions	The CPO applies pauses/reductions/updated setpoints.	EXECUTE	CPO	EV user	IE-2.3
2.5	Verify	Delivery monitoring	Delivered response vs. requested is verified.	REPORT	CPO	DSO/TSO/AI system	IE-2.4
2.6	Report	Post-event report	KPIs and compliance shared.	CLOSE	AI system	DSO/TSO/CPO	IE-2.5

Scenario							
Scenario name:		No. 3 - Multi-Vendor Aggregation					
Step No.	Event	Name of process/ activity	Description of process/ activity	Service	Information producer (actor)	Information receiver (actor)	Information exchanged (IDs)
3.1	Start	Session request	The user requests a charge via platform.	REPORT	EV user	Multi-vendor platform	IE-3.1
3.2	Vendor query	Availability and tariff lookup	The platform queries integrated CPOs for status/tariffs/constraints.	GET	Multi-vendor platform	CPO	IE-3.2
3.3	Select	Vendor selection	Best CPO is chosen (price, capacity, constraints).	EXECUTE	Multi-vendor platform	CPO	IE-3.3
3.4	Execute	Session run and monitoring	The session is delivered according to the optimal schedule and monitored throughout.	EXECUTE	AI system/CPO	EV user	IE-3.4
3.5	Close and settle	Session closure	The charging session ends and key session data are recorded for analysis.	CLOSE	CPO	AI system/EV user	IE-3.5

Information exchanged

Information exchanged		
Information exchanged, ID	Name of information	Description of information exchanged
IE-1.1	EV Plug-in and session context	Vehicle/user identifiers, connector ID, initial SOC, timestamp, requested energy or target SOC, user preferences.
IE-1.2	Grid and price snapshot	Live grid constraints and signals (DSO/TSO), congestion/limit forecasts, tariffs/price signals, generation levels.
IE-1.3	Optimized charging proposal	AI-computed schedule (start window, stop window, power profile), expected finish SOC/time, estimated cost, optional flexibility opt-in offer
IE-1.4	User consent and edits	User acceptance or edits to the proposal (departure time, price limit, minimum state of charge), plus consent confirmations.
IE-1.5	Charging setpoint command	Concrete charger instructions from the charging station operator: target power or current over time, ramp limits, start and stop triggers.
IE-1.6	Telemetry and session status	Real-time power, energy delivered, estimated state of charge, session state (running, paused, error), events and alerts.
IE-1.7	Session closure summary	Stop reason, final state of charge, total energy, duration, total cost, and any exception log.
IE-2.1	Flexibility request (grid)	Formal request from the DSO/TSO specifying service type (load reduction, load shifting, or increase), magnitude, start time, duration, affected locations or feeders, validation rules, and compensation terms.

IE-2.2	Re-optimized session updates	Updated schedules for affected sessions, including new setpoints, curtailment windows, and expected impact on the user.
IE-2.3	User adjustment notice	Notification to the user about the charging adjustment (revised completion time, revised cost, and any incentive), with the option to override where policy allows.
IE-2.4	Flexibility delivery report	Delivered response versus requested response (time-stamped power and energy), baseline used, compliance assessment, and event outcome.
IE-2.5	Post-event report on indicators	Aggregated indicators and details for the event (peak reduction, response time, user impact, compensation).
IE-3.1	Multi-vendor session request	Request from the user or platform: location, connector type, vehicle capabilities, state of charge, desired finish time, and preferences.
IE-3.2	Vendor capability and offer	Per-operator response: availability, station constraints, quoted tariff, expected completion time, and reference to any site grid constraints.
IE-3.3	Vendor selection decision	Selected operator and selection rationale.
IE-3.4	Session execution and monitoring feed	Confirmation of the applied schedule plus live telemetry and any exceptions for the running session.
IE-3.5	Session closure record	Final session data (timestamps, duration, delivered energy, applied schedule, status codes) stored for reporting and analysis.

Common terms and definitions

Common terms and definitions	
Term	Definition
AI	Artificial intelligence
AI System	Software layer responsible for analysing data and generating recommendations
CPO	Charge Point Operator – manages and controls charging stations
DSO/TSO	Distribution/Transmission System Operator – grid operators at various levels
DR	Demand response
EV	Electric vehicle
Flexibility Service	Temporary change in charging behaviour to support grid operations
HLUC	High-level use case
PUC	Primary use case
SOC	State of charge
SUC	Specialized use case
VPP	Virtual power plant

II.X HLUC10 – Coordinated charging in a virtual power plant setup

Description of the use case

Name of the use case

Use case identification		
ID	Area/Domain(s)/Zone(s)	Name of use case
HLUC10	Area: Energy system Domain: Distribution system Zone: operation	Coordinated charging in a virtual power plant setup

Version management

Version management			
Version No.	Date	Name of author(s)	Changes
0.0	05.09.24	Marzio Barresi (POLIMI)	First template provided
0.1	26.02.25	Julian Mittag (DTU)	First draft of HLUC10
0.2	15.10.2025	Julian Mittag (DTU)	Second draft HLUC10
0.3	22.10.25	Marzio Barresi (POLIMI)	Final draft version of HLUC10

Scope and objectives of use case

Scope and objectives of use case	
Scope	The High-Level Use Case (HLUC) focuses on the implementation and testing of coordinated charging in a virtual power plant (VPP) setup. The virtual power plant consists of a battery energy storage system (BESS), renewable energy sources (RESs) including wind power and solar photovoltaic, and slow and fast electric vehicle (EV) chargers, and is intended to facilitate the provision of flexibility services to the distribution system. The use case consists of three primary use cases (PUCs): • PUC10.1: Control of the VPP for the Provision of Flexibility Services • PUC10.2: Testing of Control/Dispatch Algorithms • PUC10.3: Testing of Autonomous Control for Transmission System Operator-Distribution System Operator (TSO)-(DSO) Grid Service Coordination The use case is applied to the demo site in Nordic Europe, at the Risø campus in Denmark. One Specialized Use Cases (SUCs) will be derived according to demo site: • SUC10.1 Nordic Europe demo – Risø campus (light-duty EVs with workplace charging and highway fast charging, combined with BESS and RESs).
Objective(s)	1. Review of control and communication infrastructure for virtual power plant (VPP) 2. Implementation and testing of control/dispatch algorithms for VPP operation and the delivery of flexibility services 3. Implementation and testing of autonomous control for the coordination of TSO-DSO grid services

[Narrative of use case](#)

<i>Narrative of use case</i>	
Short description	
The use case aims to review, implement and test control methods and algorithms for controlled charging of light-duty electric vehicles in a VPP setup, consisting of slow and fast chargers, as well as a BESS and RES system, with the goal of flexibility provision to the DSO.	
Complete description	
The use case focuses on the comprehensive review, implementation, and testing of advanced control methods and algorithms designed for the controlled charging of light-duty EVs within a VPP setup. This setup includes both slow and fast chargers, a BESS, and a RES system. The system will be implemented at the Nordic European Demo site in Denmark, at the Risø Campus of the Technical University of Denmark.	
The primary objective is to provide flexibility services to the DSO. By integrating these components in the form of a VPP, the system aims to optimize the charging processes, enhance grid stability, and ensure efficient energy management.	
The project will explore various strategies to achieve different goals in terms of grid services, as will be defined in WP3 of the AHEAD project. This includes balancing the load, mitigating peak demand, and maximizing the utilization of renewable energy, and other possible services, ultimately contributing to a more sustainable and resilient power grid.	

[Related primary use case](#)

<i>ID</i>	<i>Name</i>	<i>Description</i>
PUC10.1	Investigation of Control Methods for Flexibility Provision via a VPP	Review of control methods for VPP, in the context of a system that combines RESs, BESS and slow and fast chargers. Understanding best practices for VPP flexibility provision.
PUC10.2	Control/Dispatch Algorithms for VPP Operation	Implementation and thorough testing of control/dispatch algorithms for VPP operation. Evaluation of compliance, results and performance.
PUC10.3	Autonomous Control for TSO-DSO Grid Service Coordination	Implementation and thorough testing of autonomous control for TSO-DSO grid service coordination. Evaluation of compliance, results and performance.

[Related specialized use case](#)

<i>ID</i>	<i>Name</i>	<i>Description</i>
SUC10.1	Nordic Europe demo – Risø campus (light-duty EVs with workplace slow charging and highway fast-charging)	The control methods and algorithms for the VPP will be tested at the DTU Risø campus. The end-users of the charging infrastructure are DTU employees and general public.

[Key performance indicators \(KPI\)](#)

<i>Key performance indicators</i>			
<i>ID</i>	<i>Name</i>	<i>Description</i>	<i>Reference to mentioned use case objectives</i>
KPI10.1	Qualitative Services	Which services can be delivered from the VPP to the distribution grid?	Objective 2 and Objective 3

KPI10.2	Quantitative Services	To which extent can services be delivered to the distribution grid?	
KPI10.3	Energy imported from the grid	Amount of energy imported from the grid in kWh	
KPI10.4	Energy exported to the grid	Amount of energy exported to the grid in kWh	
KPI10.5	Charging session statistics	Number of charging sessions, duration, time, power, energy.	
KPI10.6	Operational CO2 Emissions	Amount of CO2 saved, due to charging based on RES, comparison to grid and internal combustion engine (ICE) vehicle.	
KPI10.7	Self-consumption rate	The amount of energy from the RES that can be consumed with the slow/fast chargers.	
KPI10.8	Self-sufficiency rate	The share of electricity consumed by the chargers that is provided directly from RES	
KPI10.9	Charging cost savings	How much the charging cost can be reduced by having an additional revenue income stream from services to the power grid	
KPI10.10	Communication and control reaction time	Time is necessary for the communication and control algorithms, time delay for the reaction of chargers	

Use case conditions

<i>Use case conditions</i>
Assumptions
Sufficient usage of the charging infrastructure at the demonstration site.
Prerequisites
Timely installation of the hardware (BESS and fast charger).
Controllable infrastructure.
Sufficient measurement infrastructure.

Further information to the use case for classification/mapping

<i>Classification information</i>
<i>Relation to other use cases</i>
The use case is highly related to HLUC1, HLUC2, HLUC5, HLUC7 and HLUC11. It can be seen as a combination of the use cases that are implemented specifically in the Nordic European Demonstration, where the charging infrastructure of slow and fast chargers is combined with a battery system as a buffer and RES as an energy source.
<i>Level of depth</i>
HLUC10 - Coordinated charging in a virtual power plant setup - PUC10.1 – Investigation of Control Methods for Flexibility Provision via a VPP - PUC10.2 – Control/Dispatch Algorithms for VPP Operation - PUC10.3 – Autonomous Control for TSO-DSO Grid Service Coordination - SUC10.1 – Nordic European demo – Risø campus (light-duty EVs with workplace slow charging and highway fast-charging)
<i>Prioritisation</i>

High priority for the AHEAD project due to the need to coordinate BESS/RES/EV charging as a VPP and validate flexibility delivery (including autonomous TSO–DSO coordination).

Generic, regional or national relation

Generic: VPP control concepts, coordinated charging methods, DSO-oriented flexibility services.

National/Regional: TSO service models and market arrangements specific to the Nordic synchronous area and Danish regulations.

Nature of the use case

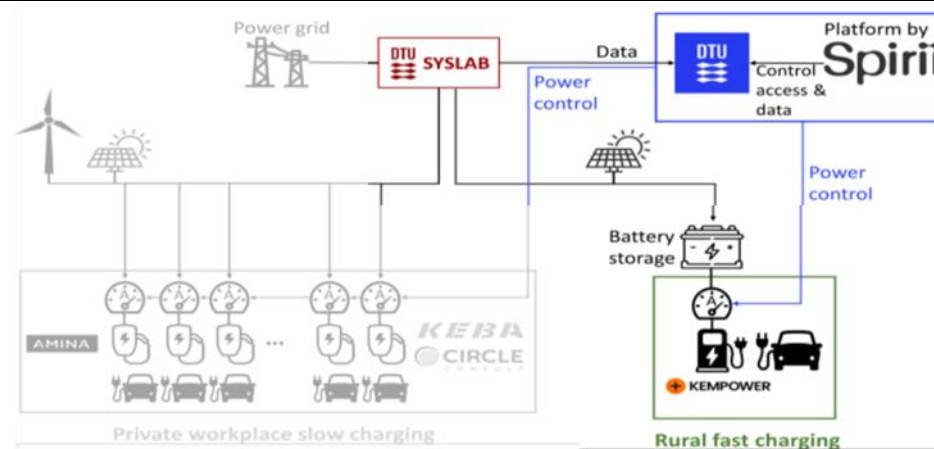
Technical/system use case; business use case (service design and operational integration).

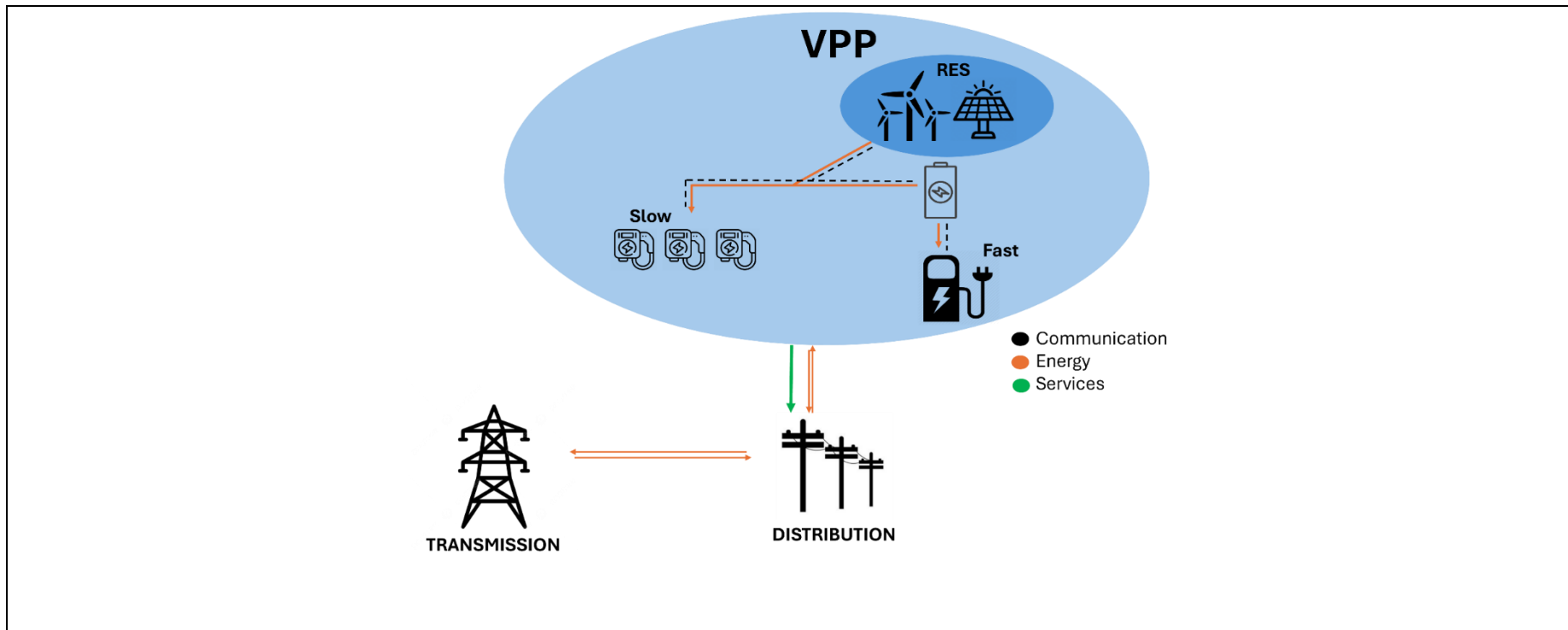
Further keywords for classification

Virtual Power Plant, coordinated charging, flexibility services, autonomous control, DSO–TSO coordination

Diagram of use case

Diagram(s) of use case





Technical details

Actors

Actors			
Grouping		Group description	
Users		End customers initiating charging sessions.	
Actor name	Actor type	Actor description	Further information specific to this use case
EV Owner	Human Actor	Individual using the charging site; arrives, connects, and requests a charging session.	Slow workplace chargers mainly for DTU staff; fast charging available to the public at Risø.

Actors

Grouping		Group description	
Site assets and resources		On-site energy assets that supply, buffer, and report status to the VPP.	
Actor name	Actor type	Actor description	Further information specific to this use case
RES Plant (PV/Wind)	System Actor	Local renewable generation providing real-time production status and accepting curtailment commands.	PV and wind installed at DTU Risø/SYSLAB; exposes telemetry to VPP and DSO.
BESS	System Actor	Battery Energy Storage System used for buffering, peak shaving, and service delivery; receives setpoints and reports state of charge.	Co-located at Risø/SYSLAB; coordinated by the VPP Controller.

Actors			
Grouping		Group description	
Site control and operations		Operational entities that run charging sessions and interface with users and assets.	
Actor name	Actor type	Actor description	Further information specific to this use case
Charge Point Operator (CPO)	Business Actor	Charging site operator responsible for operating the chargers, handling session start/stop, and forwarding session context to the VPP.	Site operations for workplace/fast chargers at Risø.
VPP Controller/Aggregator	System Actor	Central controller that plans and dispatches setpoints to chargers, BESS, and RES in line with grid and site constraints.	Computes/dispatches profiles; monitors execution; compiles reports/KPIs.

Actors			
Grouping		Group description	
Grid stakeholder		External grid entity providing limits/requests.	
Actor name	Actor type	Actor description	Further information specific to this use case
DSO	Business Actor	Distribution system operator interfacing with the site; receives visibility, issues flexibility requests, and validates delivery.	Local DSO for the Risø connection (Cerius/Radius, DTU Syslab internal grid); interacts with the VPP Controller.
TSO	Business Actor	Transmission system operator responsible for system-level stability.	May originate system service requests that are relayed/authorized via the DSO and considered by the VPP.

Step-by-step analysis of use case

[Overview of scenarios](#)

Scenario conditions

No.	Scenario name	Scenario description	Primary actor	Triggering event	Pre-condition	Post-condition
1	VPP Charging	EVs arrive(s) at fast/slow chargers to charge, wind power and solar power is producing, the entire setup is controlled as a VPP	VPP Controller/Aggregator	EV arrival/plug-in	Chargers online; RES/BESS available; platform connected.	Charging delivered; VPP constraints respected.
2	VPP Flexibility delivery	The VPP adjusts operation to provide a flexibility service to the distribution grid.	VPP Controller/Aggregator	DSO issues a flexibility request	Active VPP operation; controllable chargers, RESs, BESS; communication available.	Requested response delivered and logged; grid condition improved; site returns to normal operation.

[Steps-scenarios](#)

Scenario							
Scenario name:		No. 1 - VPP Charging					
Step No.	Event	Name of process/activity	Description of process/activity	Service	Information producer (actor)	Information receiver (actor)	Information exchanged (IDs)
1.1	RES Production	RES production status	PV and wind generate electricity; status is made available for VPP control and grid visibility.	REPORT	RES plant	VPP Controller/Aggregator; DSO	IE-1.1
1.2	EV arrives	EV arrival	The EV arrives at a) slow or b) fast charger.	REPORT	EV Owner	CPO	IE-1.2
1.3	Connection detected	Register EV connection	The charging infrastructure establishes a connection to the EV and prepares charging process.	CREATE	CPO	EV Owner	IE-1.3
1.4	Charging session request	Charging request submit	The EV requests charging based on state of charge (SOC)/need.	REPORT	EV Owner	CPO	IE-1.4
1.5	Handoff to VPP	Session context to VPP	CPO forwards session context (EV, connector, SOC, requested energy/window) and asks for a charging plan.	GET	CPO	VPP Controller/Aggregator	IE-1.5
1.6	Charging starts	Charging start	The VPP starts the session and coordinates power flows within RES, BESS, charger(s), and grid limits.	EXECUTE	VPP Controller/Aggregator	CPO; RES plant, BESS, DSO	IE-1.6
1.7	Charging session	Charging adjustments	The VPP supervises the session and adjusts charger setpoints based on RES output/BESS state/grid constraints.	CHANGE	VPP Controller/Aggregator	CPO; RES plant, BESS, DSO	IE-1.7
1.8	End of session	End of charging session	Charging finishes; EV disconnects and departs; session is closed and logged.	CLOSE	CPO	EV Owner; VPP Controller/Aggregator	IE-1.8

Scenario							
Scenario name:		No. 2 - VPP Flexibility delivery					
Step No.	Event	Name of process/activity	Description of process/activity	Service	Information producer (actor)	Information receiver (actor)	Information exchanged (IDs)
2.1	Baseline operation	VPP operating snapshot	Current operating point of chargers/RES/BESS is made available for control and grid visibility.	REPORT	VPP Controller/Aggregator	DSO; CPO; RES plant; BESS	IE-2.1
2.2	Flexibility request issued	Flexibility request	The DSO requests a flexibility service.	CREATE	DSO	VPP Controller/Aggregator	IE-2.2
2.3	Autonomous TSO–DSO clearance (optional)	Autonomy authorization and system need	If the DSO request originates from a TSO system service, the DSO validates local constraints and forwards the TSO parameters. The VPP is authorized to respond autonomously within a pre-agreed operating envelope (policy-defined limits, no manual intervention required).	REPORT	DSO; TSO	VPP Controller/Aggregator	IE-2.3
2.4	Assess and plan	Feasibility and dispatch plan	VPP validates feasibility versus constraints and prepares a component-level dispatch plan.	EXECUTE	VPP Controller/Aggregator	-	IE-2.4
2.5	Dispatch setpoints	Adjustment instructions	VPP sends updated setpoints (chargers curtail/shift, BESS charge/discharge, RES curtail if needed) to satisfy the DSO request.	EXECUTE	VPP Controller/Aggregator	CPO; RES plant; BESS	IE-2.5
2.6	Deliver response	Flexibility delivery	Assets follow setpoints during the requested window; telemetry is streamed.	REPORT	CPO; RES plant; BESS, DSO	VPP Controller/Aggregator	IE-2.6
2.7	Resume normal	Return to normal operation	After the event, VPP restores assets to optimal operation based on RES output and site needs.	CHANGE	VPP Controller/Aggregator	CPO; RES plant; BESS	IE-2.7
2.7	Post-event report	Reporting and KPIs	Event summary and KPIs are logged and shared.	CLOSE	VPP Controller/Aggregator	CPO; RES plant; BESS, DSO	IE-2.8

Information exchanged

Information exchanged

Information exchanged, ID	Name of information	Description of information exchanged
IE-1.1	RES production status	Real-time status from the RES plant (PV/wind): active/reactive power, availability, curtailment status; optionally short-term forecast.
IE-1.2	EV arrival notification	Arrival/check-in at the site: timestamp, location/charger identifier, anonymized vehicle/session identifier.
IE-1.3	Connection registration data	Connector ID, connection setup/readiness status, initial meter reading, safety interlock status.
IE-1.4	Charging request details	User/session request: initial SOC, requested energy or target SOC, desired departure time/window, user constraints/preferences.
IE-1.5	Session context to VPP	Aggregated context forwarded by the CPO to the VPP: session ID, charger/connector, vehicle/session attributes, initial SOC, requested energy/window, site constraints.
IE-1.6	Start/setpoint command (initial)	VPP instruction to start the session and initial setpoints for charger power profile; may include coordinated initial setpoints for BESS/RES respecting grid limits.
IE-1.7	Real-time adjustment commands	VPP adjustments during the session: increase/decrease/pause/resume charger power; updated BESS charge/discharge and RES curtailment commands based on asset state and grid constraints.
IE-1.8	Charging completion summary	End-of-session summary: stop reason, final SOC, energy delivered, duration, timestamps, notable events/exceptions.
IE-2.1	VPP operating snapshot	Baseline operating point before a flexibility event: per-asset power, BESS SOC/limits, charger loads, current RES output, relevant site/grid limits.
IE-2.2	Flexibility service request	Formal request from the DSO: service type (load reduction/shift/increase), magnitude, start time and duration, affected location/feeders, verification method, settlement rules.
IE-2.3	Autonomy authorization and TSO parameters (optional)	If the request originates from the TSO, the DSO forwards TSO service parameters and authorizes autonomous VPP response within a pre-agreed operating limit.
IE-2.4	Feasibility and dispatch plan	VPP's component-level plan to meet the request: targeted charger curtail/shift, BESS charge/discharge profile, RES curtailment (if needed), expected impact and risks.
IE-2.5	Setpoint dispatch for flexibility	Executable setpoints to assets to deliver the requested response: time-stamped power targets/ramps for chargers, BESS, and RES.
IE-2.6	Delivery telemetry during event	Time-stamped delivered power/energy per asset during the event; session states and exceptions, for live monitoring and later verification.
IE-2.7	Return-to-normal directive	Commands and parameters to restore standard operation: resume charging schedules, updated VPP optimization targets, BESS recovery SOC target, re-queuing/deferred session handling, and end-of-event timing.
IE-2.8	Post-event report and KPIs	Requested vs delivered power/energy, response time, compliance, grid impact (e.g., peak reduction), asset use, affected sessions, user-impact notes, and any compensation details.

Common terms and definitions

Common terms and definitions	
Term	Definition
Autonomous response	Pre-authorized VPP action to a grid request without manual intervention, within defined operating limits.
BESS	Battery energy storage system
CPO	Charge Point Operator – manages and controls charging stations
DSO/TSO	Distribution/Transmission System Operator – grid operators at various levels

EV	Electric vehicle
Flexibility Service	Temporary change in charging behaviour to support grid operations
HLUC	High-level use case
PUC	Primary use case
RES	Renewable energy source
SOC	State of charge
SUC	Specialized use case
VPP	Virtual power plant

II.XI HLUC11 – Activation of flexibility services by distribution system operators

Description of the use case

Name of the use case

Use case identification		
ID	Area/Domain(s)/Zone(s)	Name of use case
HLUC11	Area: energy system Domain: distribution system Zones: operation, DSO area	Activations of Flexibility services by distribution system operator

Version management

Version management			
Version No.	Date	Name of author(s)	Changes
0.0	05.09.24	Marzio Barresi (POLIMI)	First template provided
0.1	03.02.25	Blaž Dobravec (EG)	First draft of HLUC11
0.2	19.03.25	Blaž Dobravec (EG)	Second draft of HLUC11
0.3	08.07.25	Blaž Dobravec (EG)	Third draft of HLUC11
0.4	20.08.25	Blaž Dobravec (EG)	Fourth draft of HLUC11
0.5	22.10.25	Marzio Barresi (POLIMI)	Final draft version of HLUC11

Scope and objectives of use case

Scope and objectives of use case	
Scope	This High-Level Use Case (HLUC) focuses on the activation and management of electric vehicle (EV) flexibility services within the distribution system by the Distribution System Operator (DSO). It defines how the DSO monitors grid conditions and triggers flexibility measures—through coordinated adjustments in EV charging—to maintain grid stability and optimize energy flows. Three Primary Use Cases (PUCs) will be derived from this HLUC: • PUC11.1 – Real-Time Grid Monitoring for Flexibility Activation • PUC11.2 – Automated Communication of Flexibility Requests • PUC11.3 – Feedback and Verification of Activated Flexibility Measures Three Specialized Use Cases (SUCs) will be derived according to demo site: ▪ SUC11.1 – Nordic Europe demo ▪ SUC11.2 – Western Europe demo ▪ SUC11.3 – Southern Europe demo

Objective(s)	• Grid Stabilization: Enable the DSO to actively manage load peaks and fluctuations by activating flexibility services. • Optimized Demand Response: Adjust EV charging patterns (e.g., delayed charging, reduced charging rates, or controlled vehicle-to-grid (V2G) operations) to alleviate grid stress during high-demand periods. • Enhanced Communication: Establish a real-time communication framework between the DSO, charging aggregators, and EV charging stations.
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[Narrative of use case](#)

Narrative of use case
Short description This use case describes how the DSO detects grid overloading (during peak load periods) and activates flexibility services by sending control signals to an aggregated EV charging network. The response from EVs or charging stations helps to shift or reduce load, thereby contributing to overall grid stability.
Complete description In a modern, smart distribution system, the DSO continuously monitors grid conditions through a combination of sensors and advanced analytics. When the system identifies an impending overload or a rapid change in renewable generation (for example, a sudden drop in wind power), the DSO triggers an activation of flexibility services. Upon detection of the critical grid condition: 1. The DSO issues a flexibility activation command through a secure, real-time communication channel to the EV charging aggregator. 2. The aggregator then disseminates this command to all connected Charge Point Operators (CPOs) and, indirectly, to EV users. 3. EV charging stations adjust their charging profiles—this may include delaying the start of a charging session, reducing the charging current, or (if supported) activating V2G discharge. 4. EV users are notified about the change and, if applicable, may receive incentives for their participation. 5. Once the grid condition stabilizes, the system gradually reverts the charging profiles to normal operation and records the performance data for further analysis. This approach not only supports grid reliability but also provides valuable insights into the responsiveness and potential benefits of demand-side management initiatives within the distribution network. From a business perspective, the workflow puts demand-side flexibility into practice to optimize grid operations, supports the integration of electromobility into smart grids by aligning EV charging with system needs, and delivers cost-effective congestion management at the distribution level through measurable, compensated adjustments.

[Related primary use case](#)

ID	Name	Description
PUC11.1	Real-Time Grid Monitoring for Flexibility Activation	Focuses on detecting grid stress conditions and triggering flexibility actions.
PUC11.2	Automated Communication of Flexibility Requests	Details the protocols and interfaces for transmitting activation commands from the DSO to the aggregator.
PUC11.3	Feedback and Verification of Activated Flexibility Measures	Covers the collection and analysis of performance data post-activation to confirm the effectiveness of the actions.

[Related specialized use case](#)

ID	Name
SUC11.1	Nordic Europe demo
SUC11.2	Western Europe demo
SUC11.3	Southern Europe demo

[Key performance indicators \(KPI\)](#)

Key performance indicators			
ID	Name	Description	Reference to mentioned use case objectives
KPI11.1	Load Reduction Achieved	Measured reduction in load (in kW or percentage) during flexibility activation.	Validates the impact on grid stabilization.
KPI11.2	Activation Response Time	Average time from grid stress detection to transmission of the activation command.	Ensures rapid response for grid stabilization.
KPI11.3	Participation Rate	Percentage of EVs responding positively to the flexibility command	Optimized Demand Response, Engagement
KPI11.4	Communication Latency	Time between DSO command issuance and receipt at aggregator	Enhanced Communication

[Use case conditions](#)

Use case conditions
Assumptions
The DSO operates a real-time grid monitoring system with sufficient accuracy to detect load imbalances, or uses predictive algorithms that forecast rising load.
The EV charging aggregator and participating CPOs have communication modules capable of receiving and executing activation commands.
Prerequisites
Real-time access to grid, market, and EV charging data.
All operations comply with national and regional energy regulations and standards that permit and support flexibility activations.
Agreements are in place between the DSO, aggregators, CPOs, and EV users.

[Further information to the use case for classification/mapping](#)

Classification information
Relation to other use cases
The use case is highly related to HLUC1, HLUC7, HLUC8, HLUC9, HLUC10 and HLUC12.
Level of depth
HLUC11 - Activations of flexibility services by distribution system operators - PUC11.1 – Real-Time Grid Monitoring for Flexibility Activation - PUC11.2 – Automated Communication of Flexibility Requests - PUC11.3 – Feedback and Verification of Activated Flexibility Measures

- SUC11.1 – Nordic Europe demo
- SUC11.2 – Western Europe demo
- SUC11.3 – Southern Europe demo

Prioritisation

High: identified in the draft 2025 EU Network Code on Demand Response as a key enabler of distribution-level flexibility. In Slovenia, it is prioritised for short-term deployment (2025–2027) in the national DSO development plan.

Generic, regional or national relation

Conceptually generic and repeatable across EU-27. Aligned with:

- EU Clean-Energy Package (Directive 2019/944, Regulation 2019/943)
- National Energy Act amendments (2024) that transposed Article 32 on aggregation and customer engagement.
- Ongoing European projects (e.g. InterFlex, OneNet) that pilot similar EV-flexibility schemes.

Nature of the use case

- Operational: real-time detection of grid stress, automated issuance of flexibility signals.
- Technical: interoperability via IEC 61850-90-8, IEC 63110, ISO 15118-20, OCPI 3.0; cyber-security per IEC 62351 and ISO/IEC 27019.
- Regulatory/Market: complies with national ancillary-services rules; settlement follows ENTSO-E Harmonised Electricity Market Role Model.

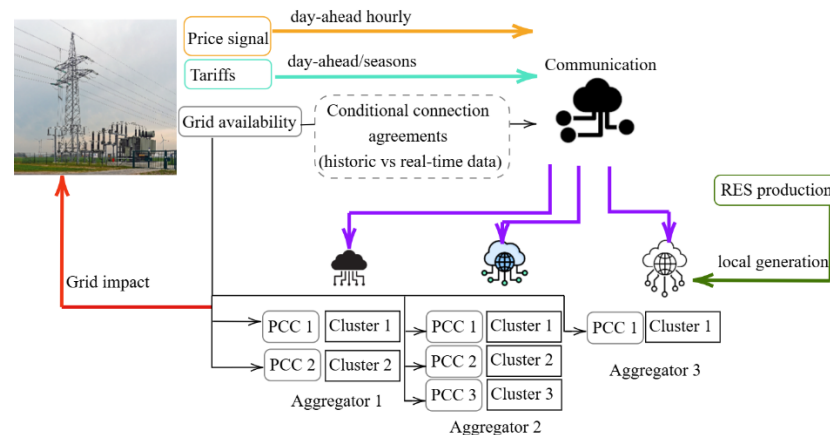
Further keywords for classification

Flexibility, EV, DSO, Aggregator, Demand Response, Smart Grid

Diagram of use case

Diagram(s) of use case

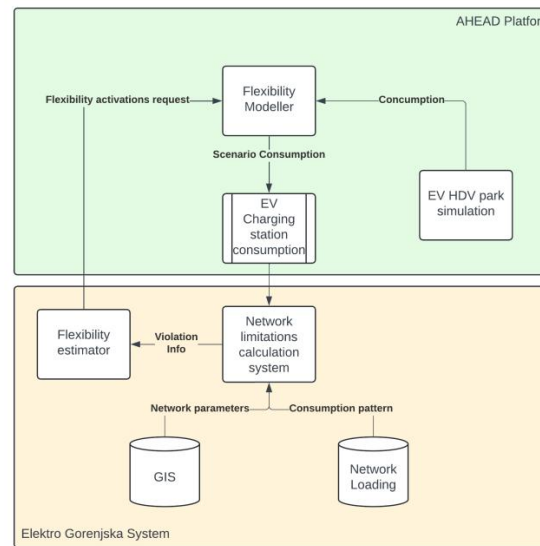
SUC11.1: Nordic Europe demo



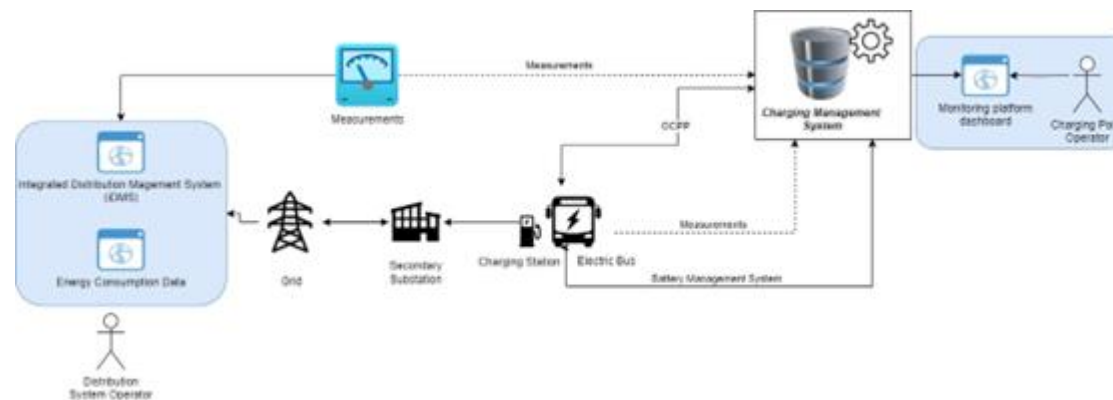
SUC11.2: Western Europe demo

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SUC11.3: Southern Europe demo (Milan)



Technical details

Actors

Actors			
Grouping		Group description	
Users		End customers initiating charging sessions.	
Actor name	Actor type	Actor description	Further information specific to this use case
EV User	Business Actor	Owner/operator of an electric vehicle whose charging may be adjusted during activations.	Receives notifications about adjustments and any incentives/options permitted by policy.

Actors			
Grouping		Group description	
Site control and operations		Operational entities that run and adjust charging sessions and interface with users and assets.	
Actor name	Actor type	Actor description	Further information specific to this use case
EV Charging Aggregator	Logical Actor	Central platform coordinating between the DSO and charging networks; routes commands and consolidates results.	Forwards DSO requests to participating CPOs, aggregates event measurements, and reports back to the DSO.
CPO	Business Actor	Operates charging sites and manages sessions at chargers.	Applies control instructions (power limits/pauses/ramps) to charging stations and informs users when required.
Charging Station (Electric Vehicle Supply Equipment (EVSE))	System Actor	On-site charging equipment that enforces control commands.	Implements station-level setpoints (power/current limits, ramps, pause/resume) and reports session status to the CPO/aggregator.

Actors			
Grouping		Group description	
Grid stakeholder		External grid entity providing limits/request	
Actor name	Actor type	Actor description	Further information specific to this use case
DSO	Business Actor	Monitors grid conditions and initiates flexibility activations to maintain grid stability.	Issues activation requests (targets, timing, verification), receives aggregated response reports, and closes the event.

Step-by-step analysis of use case

Overview of scenarios

Scenario conditions

No.	Scenario name	Scenario description	Primary actor	Triggering event	Pre-condition	Post-condition
1	Flexibility Activation During Peak Load	The DSO detects an impending overload or rapid change in grid conditions and activates flexibility services to adjust EV charging behaviour across the network.	DSO	Detection of grid stress or imbalance	Real-time grid monitoring data available; all communication systems operational.	Flexibility activation command is sent, executed, and grid load is reduced.

[Steps-scenarios](#)

Scenario							
Scenario name:		No. 1 - Flexibility Activation During Peak Load					
Step No.	Event	Name of process/activity	Description of process/activity	Service	Information producer (actor)	Information receiver (actor)	Information exchanged (IDs)
1.1	Grid Stress Detection	Monitoring Grid Conditions	The DSO detects grid stress or imbalance using real-time analytics	REPORT	DSO	-	IE-1.1
1.2	Issue activation	Flexibility activation request	The DSO sends a formal flexibility activation request with target, timing, and verification method.	CREATE	DSO	EV Charging Aggregator	IE-1.2
1.3	Forward request	Command relay to CPOs	The EV Charging Aggregator forwards the activation request to participating CPOs.	EXECUTE	EV Charging Aggregator	CPO	IE-1.3
1.4	Apply control	Charging profile adjustment	CPOs apply power limits/pauses/ramps at charging stations (EVSE).	EXECUTE	CPO	Charging Station (EVSE)	IE-1.4
1.5	Inform users	User notification	Users are notified of adjustments and any incentives/options allowed by policy.	REPORT	CPO (or EV Charging Aggregator)	EV User	IE-1.5
1.6	Track delivery	Delivery monitoring	CPOs provide measured power/energy during the event to the Aggregator.	REPORT	CPO	EV Charging Aggregator	IE-1.6
1.7	Verify response	Compliance and performance check	The Aggregator compiles delivered response vs. request and reports to the DSO.	REPORT	EV Charging Aggregator	DSO	IE-1.7
1.8	Close event	Event closure and logging	The DSO closes the activation; final records are stored for analysis.	CLOSE	DSO	EV Charging Aggregator	IE-1.8

Information exchanged

<i>Information exchanged</i>		
<i>Information exchanged, ID</i>	<i>Name of information</i>	<i>Description of information exchanged</i>
IE-1.1	Grid status and forecast snapshot	Measured load, voltage, transformer loading, constraint alarms, and short-term forecast indicating the expected overload window.
IE-1.2	Flexibility activation request	Formal request parameters: requested action (reduce/shift/increase), target magnitude, start time, duration, affected location/feeders, verification method, and any incentive rules (if applicable).
IE-1.3	Aggregator dispatch to CPOs	Per-site targets and instructions derived from the request: power limits or ramps, time window, priority rules, and user communication policy to apply.
IE-1.4	Charging control instruction	Station-level control parameters: maximum power or current, ramp limits, pause/resume rules, start/stop triggers, and expected completion adjustments.
IE-1.5	User notification content	Reason for the change, expected impact on charging (delay or reduced rate), revised completion estimate, and incentive or opt-out options where policy allows.
IE-1.6	Event delivery measurements	Time-stamped power and energy per site/session during the event, state changes, and any exception logs needed for later verification.
IE-1.7	Aggregated response report	Requested versus delivered reduction/shift, baseline used, compliance score, response time, and summary of affected sessions.
IE-1.8	Event closure record	Final status of the activation: start/end times, assets involved, issues encountered, references to stored datasets, and notes for audit/analysis.

Common terms and definitions

<i>Common terms and definitions</i>	
<i>Term</i>	<i>Definition</i>
CPO	Charge Point Operator – operates public/private EV charging stations
DSO	Distribution System Operator – manages local electricity distribution grid
EV	Electric vehicle
EVSE	Electric vehicle supply equipment
HLUC	High-level use case
PUC	Primary use case
SUC	Specialized use case
V2G	Vehicle-to-Grid – bi-directional energy exchange from EVs to the grid
EV	Electric vehicle

II.XII HLUC12 – Grid planning with artificial intelligence tool

Description of the use case

Name of the use case

<i>Use case identification</i>		
<i>ID</i>	<i>Area/Domain(s)/Zone(s)</i>	<i>Name of use case</i>
HLUC12	Area: energy system Domain: distribution system Zones: operation, station, field	Grid planning with artificial intelligence tools

Version management

<i>Version management</i>			
<i>Version No.</i>	<i>Date</i>	<i>Name of author(s)</i>	<i>Changes</i>
0.0	05.09.24	Marzio Barresi (POLIMI)	First template provided
0.1	04.03.25	Marzio Barresi (POLIMI)	First draft of HLUC12
0.2	30.04.25	Marzio Barresi (POLIMI), Antonio Procopio, Saverio Azzato (NTTDATA)	Second draft of HLUC12
0.3	22.10.25	Marzio Barresi (POLIMI)	Final draft version of HLUC12

Scope and objectives of use case

<i>Scope and objectives of use case</i>	
Scope	The High-Level Use Case (HLUC) focuses on optimizing the placement of electric vehicle charging stations and improving grid utilization in urban and rural areas through artificial intelligence (AI)-based decision support systems. The system integrates georeferenced data, traffic and mobility patterns, typical charging profiles, and distribution-network hosting capacity with predictive analytics to forecast network loading and charging demand; these forecasts drive a siting module that identifies and ranks optimal charger locations and sizes while explicitly accounting for grid impact and user behaviour. Three Primary Use Cases (PUCs) will be derived from this HLUC: • PUC12.1 – Spatial Mapping Model Calibration for Electric Vehicle (EV) Charging Location. Scope: test and calibrate spatial mapping models against usage patterns for feasible charging locations. • PUC12.2 – Grid Prediction Model Testing for EV Charging Integration. Scope: test grid prediction models for charging locations. • PUC12.3 – AI Techniques for Grid Planning and Optimization. Scope: test AI techniques for grid planning. Three Specialized Use Cases (SUCs) will be derived according to demo site: ▪ SUC12.1 – Nordic Europe demo ▪ SUC12.2 – Southern Europe demo

Objective(s)	▪ SUC12.3 – Western Europe demo
	1. Develop an AI-based decision support system to optimize the location of EV charging stations. 2. Maximize grid utilization by forecasting demand and supply, and balancing energy loads. 3. Use real-time data from EV users, heavy-duty vehicles (HDVs), vessels, smart meters, and grid operators to continuously improve and adapt AI models. 4. Ensure scalability and reusability of the AI models for different geographic areas and conditions. 5. Provide a clear, georeferenced visualization for stakeholders to make informed planning decisions.

[Narrative of use case](#)

Narrative of use case	
Short description	This use case develops a two-layer decision-support approach for EV charging deployment. First, a planning layer fuses geographic information system (GIS) data (georeferenced map and urban layers), traffic patterns, typical daily charging profiles, and distribution-network hosting capacity to map feasible areas. Second, an AI forecasting layer provides near-real-time predictions of charging demand and grid loading, ranking candidate sites (and sizes) by grid impact and service benefit. Together, the tools optimize siting of EVSE while safeguarding grid stability and efficient utilization.
Complete description	This use case explores the development of an AI-driven decision support system that leverages geospatial data, real-time charging behaviour analysis, and predictive analytics to optimize the deployment of charging infrastructure in a way that maximizes efficiency for both users and the energy grid. At the core of this system is the integration of spatial mapping models and AI-driven grid forecasting techniques. The process begins with the calibration of spatial mapping models, which incorporate historical charging patterns, georeferenced data, and environmental constraints to identify optimal locations for charging stations. By analysing EV user charging behaviour, HDV fleet movement trends, and vessel shore power requirements, the system pinpoints high-demand areas where new charging stations would provide the greatest benefit. These models undergo continuous refinement, integrating real-time mobility data, urban planning constraints, and energy infrastructure considerations to ensure accurate and dynamic decision-making. In parallel, the system employs grid prediction models to evaluate how newly added charging stations will affect energy distribution and grid performance. These AI-driven models analyse grid load patterns, substation capacity, transformer stress levels, and demand forecasts to determine whether a proposed charging station location is sustainable within the existing energy infrastructure. By simulating different deployment scenarios, the system ensures that new charging infrastructure does not overload the grid but instead optimizes power distribution. Where necessary, it recommends demand-side response strategies, smart charging schedules, or grid reinforcements to maintain energy balance. AI techniques for grid planning are applied to forecast future grid needs, making the system adaptable for long-term planning. The end result is a flexible and scalable solution for deploying EV charging stations, enhancing grid efficiency, and meeting the growing needs of EV users.

[Related primary use case](#)

ID	Name	Description
PUC12.1	Spatial Mapping Model Calibration for EV Charging Location	This use case focuses on testing and calibrating spatial mapping models to determine optimal locations for EV charging stations. The model integrates georeferenced data, EV user charging patterns, HDV and vessel charging behaviours, and environmental factors to identify areas with the highest demand for charging infrastructure. By analysing real-world usage patterns, the system fine-tunes its spatial mapping algorithms to ensure the chargers are placed where they are most needed. The goal is to create a more accurate and efficient placement strategy that matches the requirements of both the users and the grid.
PUC12.2	Grid Prediction Model Testing for	This use case involves testing grid prediction models to assess how EV charging stations affect grid performance. The AI-powered models analyse data from existing charging infrastructure, grid loads, and energy demand forecasts to predict how new charging stations will impact the energy grid. The models provide insights into the optimal number and location of charging stations that can

	EV Charging Integration	be added without overloading the grid, ensuring a balance between energy supply and demand. This predictive analysis helps grid operators and urban planners make informed decisions on EV infrastructure deployment.
PUC12.3	AI Techniques for Grid Planning and Optimization	In this use case, various AI techniques are applied to optimize grid planning and integration with EV charging stations. The AI models predict future energy needs based on current consumption patterns, charging behaviours, and grid capacity, helping to plan long-term grid expansion and upgrades. These techniques will be tested and validated to ensure that the grid can support the increasing demand for EV charging without compromising stability. The AI-driven planning process focuses on maximizing grid efficiency, minimizing energy waste, and optimizing resource allocation to support both EV users and grid operators.

[Related specialized use case](#)

ID	Name
SUC12.1	Nordic Europe demo
SUC12.2	Southern Europe demo
SUC12.3	Western Europe demo

[Key performance indicators \(KPI\)](#)

Key performance indicators			
ID	Name	Description	Reference to mentioned use case objectives
KPI12.1	Stakeholder trust in AI recommendations	Evaluates stakeholder acceptance of AI-generated recommendations. Measured as the ratio of accepted recommendations without major modifications to total recommendations provided.	Objective 1, 5
KPI12.2	Grid utilization improvement	Assesses the AI model effectiveness in optimizing grid load balancing, based on changes in load variance (%) before and after AI optimization in the demo.	Objective 2
KPI12.3	AI Model adaptation to increasing data availability	Measures the AI model ability to refine its recommendations as more real-time data from users, smart meters, and grid operators becomes available. Measured as the percentage change in AI-suggested charging locations and grid impact scores over multiple data update cycles, with a target deviation range of X% to indicate learning stability.	Objective 3
KPI12.4	AI Model adaptability	Assesses whether the AI model produces reliable recommendations across different countries, grid configurations, and regulatory environments, measured by the success rate of AI-generated recommendations in various test scenarios.	Objective 4
KPI12.5	Visualization clarity	Assesses how well the AI-generated georeferenced maps support decision-making. Measured through stakeholder ratings (scale 1-10) on clarity and usability.	Objective 5

[Use case conditions](#)

Use case conditions
Assumptions
The AI-based planning tool relies on georeferenced data, grid topology, charging station usage patterns, and mobility data, which are assumed to be available from distributed system operators (DSOs), municipalities, and third-party data providers.

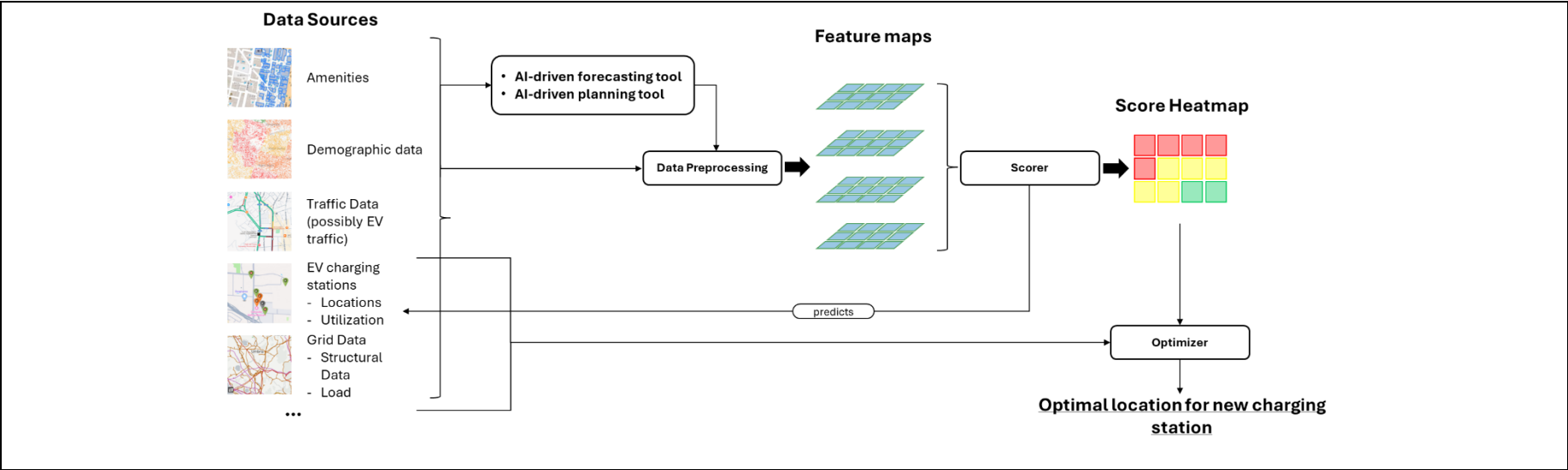
The presence of an existing network of EV, HDV, and vessel charging infrastructure is assumed, with historical usage data available for AI model training and validation.
It is assumed that grid operators will provide access to grid load data, energy consumption profiles, and network constraints to assess the feasibility of new charging station locations.
The AI tool will incorporate various layers of geospatial information, including urban characteristics and grid constraints, to optimize charging station placement.
It is assumed that the AI models will be periodically updated based on real-time data streams from smart meters, traffic sensors, and other IoT sources.
The tool is compliant with regulatory and technical standards.
Prerequisites
Prior to execution, all necessary datasets (grid topology, geospatial data, EV, HDV, and vessel charging usage, mobility patterns) must be collected, cleaned, and structured.
The grid operators must provide real-time or historical grid load data to ensure accurate forecasting of grid impact.
The AI planning tool must have predefined objectives (e.g., minimizing grid impact, maximizing accessibility) and constraints (e.g., grid limitations, land-use restrictions).
Spatial mapping and grid prediction models must be tested and validated with real-world data before deployment.

[Further information to the use case for classification/mapping](#)

Classification information
Relation to other use cases
The HLUC is highly related to HLUC1, HLUC4, HLUC8, HLUC9, HLUC10 and HLUC11.
Level of depth
HLUC12 - Grid planning with artificial intelligence tools • PUC12.1 – Spatial Mapping Model Calibration for EV Charging Location • PUC12.2 – Grid Prediction Model Testing for EV Charging Integration • PUC12.3 – AI Techniques for Grid Planning and Optimization ▪ SUC12.1 – Nordic Europe demo ▪ SUC12.2 – Southern Europe demo ▪ SUC12.3 – Western Europe demo
Prioritisation
High priority for the AHEAD project due to the need to optimize EV charging station placement and grid usage. This is both a business and technical priority, responding to new challenges in EV integration and grid management.
Generic, regional or national relation
Generic
Nature of the use case
Technical/system use case
Further keywords for classification
EV charging infrastructure, grid optimization, AI-driven planning, spatial mapping, predictive analytics, smart grid, real-time data integration

Diagram of use case

Diagram(s) of use case



Technical details

Actors

Actors			
Grouping		Group description	
AI and Decision Support Systems		This group includes actors responsible for providing and managing AI tools, models, and decision support systems used for EV charging station placement and grid optimization.	
Actor name	Actor type	Actor description	Further information specific to this use case
AI model provider	Role/Human actor	Provides AI solutions for grid planning, including spatial mapping and predictive analytics	Supplies and configures AI models for validating grid plans and usage pattern predictions
AI-based tool	Software / systems / applications / devices	The decision support system uses AI models to identify optimal locations for EV charging stations in urban and rural areas. It integrates georeferenced datasets and provides optimization forecasts.	Central to identify the best locations for charging stations, utilizing AI models and scenario analysis for decision making.

Actors	
Grouping	Group description

Operational and planning stakeholders		This group includes all the human actors involved in strategic planning, management, and operational execution related to EV charging infrastructure and grid systems.	
Actor name	Actor type	Actor description	Further information specific to this use case
Consumers	Role/Human actor	Electric vehicle consumers, HDV and vessel operators provide usage data that feeds into the AI models and are supported by the system with suggestions for improving charging services and energy use.	Usage patterns from EVs, HDVs, and electric vessels help optimize charging station locations, grid balancing, and energy demand forecasting.
Urban planner	Role/Human actor	Urban planners use the system to evaluate urban and rural areas and assess the best locations for EV charging stations, taking into account geographic, environmental, and social constraints.	Integrates urban/rural development plans with the decision support system to balance infrastructure expansion and community needs.
Distribution System Operator (DSO)	Role/Human actor	DSO is responsible for monitoring and controlling the electrical grid infrastructure. It interacts with the system to assess the impact of proposed charging stations on the grid and optimize resource allocation.	Ensures that the deployment of charging stations aligns with grid capacity and overall grid optimization goals.
Charge Point Operator (CPO)	Role/Human actor	CPOs manage the operation, maintenance, and performance monitoring of EV charging stations. They evaluate new installation opportunities and ensure the infrastructure meets service requirements.	Provides real-time data on existing infrastructure performance, influencing future placement decisions and grid impact evaluation.

Actors			
Grouping		Group description	
Data collection and infrastructure system		This group includes systems responsible for collecting and managing the data that informs AI models and decision-making for EV charging station placement and grid optimization.	
Actor name	Actor type	Actor description	Further information specific to this use case
Smart meter infrastructure	Software / systems / applications / devices	A system that collects data from various sources, including EV charging stations, EVs, HDVs, vessels, and the electrical grid. This system aggregates data such as energy consumption, charging patterns, grid load, geographic locations, and environmental conditions.	This system provides critical input for AI models, collecting real-time data on charging behaviour, station utilization, grid performance, and geospatial data. It ensures that all relevant data is centralized for analysis and optimization of the grid and charging infrastructure

Step-by-step analysis of use case

[Overview of scenarios](#)

Scenario conditions						
No.	Scenario name	Scenario description	Primary actor	Triggering event	Pre-condition	Post-condition

1	Data Collection and Integration	The AI-based tool gathers data from multiple sources, including EV users, vessels, heavy-duty vehicles, DSOs, and smart meters, to create a comprehensive dataset for analysis.	AI-based tool, Consumers, CPO, DSO, Smart Meter Infrastructure	New data collection request or scheduled periodic update	All data sources (EV usage, vessels, HDVs, grid data, geographic information system (GIS) layers) are accessible and functional.	A structured dataset is created, ready for analysis in subsequent scenarios.
2	Planning and Forecasting	City/grid context is consolidated; forecasting models are refreshed; demand forecasts and hosting-capacity bounds are computed and fused into a city-wide suitability map; planning baseline is prepared.	AI-based tool; AI model provider; Urban Planner; DSO; CPO	New planning cycle initiated or scheduled planning refresh	Structured dataset from Scenario 1 available; forecasting models configured.	Planning baseline published and shared with stakeholders; ready to feed Site Selection and Optimization (Scenario 3)
3	Site Selection and Optimization (best locations)	The AI-based tool processes georeferenced data, grid constraints, and charging station usage patterns to recommend optimal locations for new charging stations. It also integrates grid impact assessment to prevent overload and evaluates urban constraints to align with city planning regulations.	AI-based tool, Urban Planner, DSO, CPO	New request for charging station placement from a stakeholder (CPO, Urban Planner, or DSO).	AI models have been trained and validated; all necessary input data (grid topology, mobility data, urban layers) is available.	The AI tool provides a list of optimal locations with grid impact assessment and urban planning considerations, ready for stakeholder review.

[Steps-scenarios](#)

Scenario							
Scenario name:		No.1 - Data Collection and Integration					
Step No.	Event	Name of process/activity	Description of process/activity	Service	Information producer (actor)	Information receiver (actor)	Information exchanged (IDs)
1.1	Scheduled data collection	Collect charging station usage data	The AI tool gathers charging patterns from EVs, HDVs, and vessels.	GET	Consumers, CPO, Smart meter infrastructure	AI-based tool	IE-1.1
1.2	Grid data retrieval	Gather grid topology and load constraints	The AI tool retrieves power grid data, including transformer loads and network congestion.	GET	DSO, Smart meter infrastructure	AI-based tool	IE-1.2
1.3	Urban planning data retrieval	Obtain geospatial and demographic information	The AI tool gathers urban infrastructure data (e.g., land use, transport hubs, point of interest, demographics).	GET	Urban Planner, Smart meter infrastructure	AI-based tool	IE-1.3
1.4	Data processing	Clean and structure data for analysis	The AI model provider processes, normalizes, and integrates the datasets into a unified model.	EXECUTE	AI model provider	AI-based tool	IE-1.4

Scenario							
Scenario name:		No.2 - Planning and Forecasting					
Step No.	Event	Name of process/activity	Description of process/activity	Service	Information producer (actor)	Information receiver (actor)	Information exchanged (IDs)
2.1	Planning setup	Assemble city and grid context	City characteristics, traffic patterns, typical user charging profiles, grid data, and initial hosting-capacity inputs are consolidated.	GET	Urban planner; DSO; CPO	AI-based tool	IE-1.4
2.2	Model refresh	Update forecasting models	AI-driven forecasting models are trained/refreshed using the latest integrated datasets.	EXECUTE	AI model provider	AI-based tool	IE-2.1
2.3	Demand forecasting	Short/medium-term forecasts	Zone/time forecasts of charging demand are generated (daily/weekly profiles).	EXECUTE	AI-based tool	AI-based tool	IE-2.2
2.4	Hosting capacity analysis	Compute network hosting bounds	Hosting capacity is calculated per feeder/substation to reflect distribution-network limits.	EXECUTE	AI-based tool	AI-based tool	IE-2.3
2.5	Suitability synthesis	Create city-wide suitability map	Forecasts, hosting capacity, and urban constraints are combined into a suitability surface.	EXECUTE	AI-based tool	AI-based tool	IE-2.4
2.6	Stakeholder review	Share planning outputs	Maps, indicators, and rationale are shared with stakeholders for review.	REPORT	AI-based tool	Urban planner; DSO; CPO	IE-2.5
2.7	Feedback capture	Collect preferences/edits	Stakeholders provide constraints (exclusions, priorities, service-level targets) and comments.	CHANGE	DSO; Urban planner; CPO	AI-based tool	IE-2.6
2.8	Iteration (optional)	Refine planning outputs	If requested, the tool incorporates feedback and re-runs steps 2.2–2.7.	REPEAT (2.2–2.7)	-	-	-
2.9	Define baseline	Publish planning baseline	A planning baseline is issued and can be used as input to site selection (scenario 3).	CLOSE	AI-based tool	DSO; Urban planner; CPO	IE-2.7

Scenario							
Scenario name:		No.3 - Site Selection and Optimization (best locations)					
Step No.	Event	Name of process/activity	Description of process/activity	Service	Information producer (actor)	Information receiver (actor)	Information exchanged (IDs)
3.1	New planning request	Initiate charging station placement analysis	A stakeholder (CPO, Urban Planner, or DSO) submits a request to evaluate and identify optimal locations for new charging stations.	CREATE	CPO / Urban Planner / DSO	AI-based tool	IE-3.1

3.2	Preference submission	Collect stakeholder preferences	Before suggesting new placement locations, the AI tool gathers specific preferences, such as location constraints.	GET	Urban Planner / CPO / DSO	AI-based tool	IE-3.1
3.3	Baseline and feature	Generate feature map and scoring heatmap	The AI tool loads the pre-processed baseline dataset (from scenario 2), builds the spatial feature map, and computes a location-scoring heatmap that already embeds grid-hosting capacity bounds and overload risk and predicts expected charging station utilization.	GET	AI-based tool	AI-based tool	IE-3.2
3.4	Candidate generation	Identify potential charging locations	Candidates are derived from the heatmap via thresholds/clustering (demand, accessibility, hosting capacity).	EXECUTE	AI-based tool	AI-based tool	IE-3.3
3.5	Urban constraints assessment	Filter locations based on urban planning criteria	The AI tool evaluates the feasibility of the potential charging locations identified in step 2.4 by assessing regulatory, geographic, and urban planning constraints.	EXECUTE / REPORT	AI-based tool	AI-based tool / Urban planner / CPO / DSO	IE-3.4
3.6	Preliminary site validation	Review AI-suggested locations	The Urban Planner, CPO, and DSO review the AI-generated alternative locations to confirm feasibility before optimization or request further adjustments based on additional considerations and preferences, potentially triggering a new planning request.	GET / CHANGE / REPEAT (2.1 – 2.8)	Urban Planner / CPO / DSO	AI-based tool	IE-3.5
3.7	Optimization process	Adjust recommendations based on grid and urban impact	The AI tool refines the charging station placement by prioritizing locations with minimal grid impact while maximizing accessibility.	EXECUTE	AI-based tool	AI-based tool	IE-3.6
3.8	Finalization of site selection	Approve or request modifications to the plan	Stakeholders confirm the placement plan or request further adjustments based on additional considerations and preferences.	GET/CHANGE/REPORT (2.8 – 2.10)	Urban Planner / CPO / DSO	-	IE-

Information exchanged

Information exchanged		
Information exchanged, ID	Name of information	Description of information exchanged
IE-1.1	Charging session records	Data on charging station usage patterns, session duration, and energy consumption. Used for demand analysis and forecasting.

IE-1.2	Grid load and capacity data	Information on transformer loads, network constraints, congestion levels, and grid topology. Used to assess grid impact.
IE-1.3	Urban planning layers	Geospatial data on land use, transport hubs, zoning regulations, and population density. Used to ensure regulatory compliance.
IE-1.4	AI Model processed dataset	Normalized and structured dataset integrating grid, mobility, and geographic information.
IE-2.1	Forecasting model update	Updated forecasting models and metadata
IE-2.2	Demand forecast by zone/time	Short/medium-term charging demand per zone/time slice (expected sessions, energy, peak power) with optional confidence bands.
IE-2.3	Hosting capacity map	Per-feeder/substation hosting bounds: available capacity, limiting elements, and connection constraints relevant to new charging stations.
IE-2.4	Suitability map and score layers	Composite suitability surface with per-cell scores and score breakdown (demand, accessibility, hosting capacity, planning constraints).
IE-2.5	Planning outputs for review	Stakeholder package: maps, ranked areas, KPIs and assumptions.
IE-2.7	Stakeholder feedback and constraints	Collected inputs: no-build exclusions, priority zones, service-level targets, phasing, and budget bounds.
IE-2.8	Planning baseline	Versioned baseline containing the approved suitability layers, key parameters, and references for Scenario 3 site selection.
IE-3.1	New planning request ID	A unique identifier for planning requests submitted by stakeholders, including specific location preferences, constraints, and priorities for new charging stations.
IE-3.2	Charging location potential heatmap	Baseline-derived spatial layers per grid cell: feature map (demand, accessibility, planning constraints) combined with hosting-capacity bounds/overload-risk to produce a composite location score and utilization forecast.
IE-3.3	Initial charging location candidates	AI-generated list of potential charging station locations, based on demand, accessibility, and urban structure.
IE-3.4	Urban constraints analysis report	Report generated by AI that evaluates site feasibility against urban planning criteria such as land use, proximity to key points, and environmental restrictions.
IE-3.5	Stakeholder Feedback	A list of charging station locations that have passed preliminary validation by urban planners, CPOs, and DSOs. This dataset will be used as input for the optimization process. If the stakeholders request changes, the planning request cycle repeats from 2.1.
IE-3.6	Optimized charging station plan	Final AI-optimized charging station placement plan, refined through stakeholder input and comprehensive grid and urban impact assessments.
IE-3.7	Finalized charging station placement plan	The final list of charging station locations that have been approved or modified by stakeholders (Urban Planner, CPO, DSO) after reviewing AI-generated recommendations.

Common terms and definitions

Common terms and definitions	
Term	Definition
AI	Artificial intelligence
CPO	Charge point operator
DSO	Distributed system operator

EV	Electric vehicle
GIS	Geographic information system
HDV	Heavy-duty vehicle
HLUC	High-level use case
PUC	Primary use case
SUC	Specialized use case