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AHEAD

AI-informed Holistic Electric Vehicles Integration Approaches for Distribution Grids

D7.1

Final design, Nordic

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EXECUTIVE SUMMARY

Deliverable D7.1 outlines the final specifications and implementation plans for the Nordic demosites within the AHEAD project, thereby formalizing the outcomes of Task 7.1. The primary objective of the task is to provide detailed specifications of the Nordic demonstration sites and the corresponding envisioned use cases. Specifically, the demonstration infrastructure specified in this deliverable is required to support and demonstrate the integration and control of multi-brand chargers with fast chargers, in a way that allows for validation and evaluation of flexibility activation, demand response functionalities, AI tools, cybersecurity and virtual power plant coordination within the AHEAD project.

The first demonstration site located on the Risø campus of DTU focuses on the interoperability of multi-brand chargers and showcases AC smart charging for employees and visitors of the adjacent office buildings. The site hosts multi-brand chargers with a combined nominal capacity of 132 kW but operates under a constrained 43 kW grid connection. This enables tests of dynamic load sharing, demand response, and coordinated control. On top of that, the site is integrated into an environment with a 30 kW photovoltaic and a 22 kW wind installation, allowing us to exploit the synergies between renewable electricity generation and EV (smart) charging demand. The second demonstration site focuses on DC fast charging at highways in rural areas, where a 300 kWh stationary battery is used to buffer electricity drawn from the constrained 43 kW grid connection to be able to provide fast charging powers of up to 150 kW. In addition there are 30 kW of photovoltaic panels installed. This setup enables peak shaving and load shifting by charging the battery during low-demand periods and discharging during fast-charging events, resulting in a controllable testbed for evaluating battery dispatch algorithms, predictive scheduling and optimal operation under contrained grid conditions.

In the final stages of the roll-out, both demo sites are meant to be interoperable and connected to the DTU-hosted SYSLAB, allowing for control and the collection of high-resolution data across all assets. This document presents a detailed account of all planned test cases, including a description, list of objectives and linkage to individual use cases per test case. It further provides an extensive list of relevant KPIs, and a list of relevant KPIs per use case as well as what data needs to be collected for the use case analysis.

The specifications provided in this deliverable D7.1 lay the groundwork for smooth commissioning, operation and ultimately testing of the described infrastructure, execution of the test cases and evaluation of the corresponding use cases based on the defined KPIs. As such, these specifications enable the AHEAD project to progress smoothly in the following stages within WP 7.

TABLE OF CONTENTS

1 INTRODUCTION ... 8

1.1 Background and Objectives ... 8

1.2 Narrative description of the “Slow/Fast Charging Demonstration – DTU-Risø Campus” ... 8

1.3 Structure ... 10

2 FINAL SPECIFICATIONS FOR THE USE CASES ... 10

2.1 Methodological Approach ... 10

2.2 Use Cases Overview ... 10

2.3 Detailed Test Case Specifications ... 12

2.4 Roles and Responsibilities ... 25

3 PLANS FOR DEVELOPMENT, INSTALLATION AND COMMISSIONING ... 27

3.1 Scope & Objectives ... 27

3.2 Site & Assets (Summary) ... 27

3.3 Development Plan & Timeline ... 27

3.4 Electrical & Mechanical Standards, Communication Protocols, and System Concept ... 28

3.5 Installation Layout ... 30

3.6 Testing & Acceptance Criteria ... 33

4 DATA MONITORING AND ACQUISITION ... 34

4.1 Test Framework ... 35

4.2 Data structure – AMINA CHARGER ... 36

4.3 Energy management system ... 37

5 SET OF KEY PERFORMANCE INDICATORS ... 40

5.1 Introduction ... 40

5.2 Methodological Framework ... 40

5.3 KPI Categories...41
5.4 Design of surveys of EV drivers...45
6 CONCLUSION...48
REFERENCES...49
7 ANNEXES...53
7.1 Fast charging KPIs...53
7.2 Slow charging KPIs...59

LIST OF FIGURES

Figure 1 Schematic of the Nordic demo sites. 29
Figure 2 Schematic of the slow charging demonstration. 29
Figure 3 Cluster layout slow charging demonstration. 30
Figure 4 Cable layout slow charging demonstration. 31
Figure 5 Cable routing for the grid connection of the fast charging demo site. 32
Figure 6 Setup of the fast charging demonstration. 32
Figure 7 System configuration and clusters. 34
Figure 8 Testing framework overview. 36
Figure 9 First phase of EMS including Kempower EV charger and Pixii BESS. 38
Figure 10 EMS second phase, assets integrated via Modbus TCP. 38
Figure 11 In the third phase of EMS, Kempower ChargEye will be the EMS controller. 39

LIST OF TABLES

Table 1 Overview of UC1 – UC12 11
Table 2 Overview of test cases for the Nordic slow charging demonstration. 12
Table 3 Overview of test cases for the Nordic fast charging demonstration. 19
Table 4 Roles and Responsibilities for the slow charging demo. 25
Table 5 Roles and responsibilities for the fast charging demo. 25
Table 6 Development plan and timeline 27
Table 7 Testing and acceptance criteria. 33
Table 8 KPIs for fast charging demonstration. 42
Table 9 KPIs for slow charging demonstration. 44

1 INTRODUCTION

In this section, we outline the objectives, methodology, and structure of this deliverable.

1.1 Background and Objectives

The objective of Task 7.1 is to demonstrate the feasibility and combined delivery of grid services with multi-brand chargers together with hybrid resources such as fast chargers with battery energy storage and DER.

This task will consolidate the final specifications for the UCs to be demonstrated in Denmark. This will be done by assessing the current infrastructure in two locations (inside and outside Risø campus), defining plans for the development, installation, and commissioning of the hardware and software. Besides, in this task, data to be monitored and acquired in the demos will be specified. A set of KPIs will be defined for the evaluation of the main results of the demos, as well as for the comparison between different ones.

1.2 Narrative description of the “Slow/Fast Charging Demonstration – DTU-Risø Campus”

Demonstration Overview – DTU-Risø Campus

The DTU-Risø Campus hosts the Nordic AHEAD project’s main demonstration site, where both slow- and fast-charging infrastructures are deployed to test advanced management concepts, interoperability, and flexibility services for electric vehicle (EV) charging under real-world operational constraints. The site functions as a living laboratory for exploring how heterogeneous charging systems, integrated with local renewable generation, grid limitations, and intelligent control algorithms, can together enable efficient, resilient, and sustainable energy management for future e-mobility ecosystems.

Slow-Charging Demonstration

The slow-charging demonstration focuses on multi-brand AC charging management and interoperability. Installed adjacent to DTU-Risø office buildings, the setup serves a diverse community of around 500 employees, students, and visitors, reflecting typical workplace charging conditions.

The site includes Amina, Fronius, and Zaptec etc., chargers with a combined nominal capacity of approximately 132 kW, while the available grid connection is limited to only 43 kW, about one-third of the total nominal load. This intentional constraint provides an ideal environment for testing smart load management, demand response, and coordinated control mechanisms, where multiple chargers dynamically share limited power without overloading the local grid.

In addition, the site is coupled with 30kW of photovoltaic panels and a 22kW wind turbine, operating in a behind-the-meter configuration. This hybrid renewable setup supports testing of renewable-priority charging and AI-based predictive scheduling, where locally produced clean energy is prioritized for EV charging to reduce grid imports and emissions. All systems are fully integrated into DTU's SYSLAB research infrastructure, enabling 1-second-resolution monitoring and control. This allows comprehensive analysis of charger responsiveness, latency, power-tracking accuracy, and user interaction, and facilitates the comparison of different management strategies, from heuristic throttling to fully AI-driven load coordination.

Fast-Charging Demonstration

The fast-charging demonstration explores high-power DC charging integrated with stationary energy storage and renewable generation. The system includes a 150 kW fast charger connected to a 300 kWh stationary battery buffer, 30 kW of photovoltaic panels and the same 43 kW grid connection, mirroring real-world conditions in locations where grid reinforcement is limited or expensive.

This hybrid configuration enables peak shaving and load shifting, where the battery is charged during low-demand periods and discharged during peak charging events to deliver high power without exceeding the grid capacity. The result is a controllable testbed for evaluating battery dispatch algorithms, predictive scheduling, and optimal operation under constrained grid conditions.

The battery and fast charger are also coupled with local PV and wind sources, allowing investigation of renewable-powered fast charging and hybrid control strategies that minimize carbon intensity while maintaining high user satisfaction.

As with the slow-charging site, the fast-charging system is fully integrated within SYSLAB, offering synchronized, high-resolution data across all assets—charger, storage, renewables, and grid interface. This integration supports detailed evaluation of charging latency, power-sharing efficiency, SOC tracking, and trade-offs between performance, sustainability, and grid impact.

Integrated Research Framework

Together, the slow- and fast-charging demonstrations at DTU-Risø provide a comprehensive experimental platform that spans the full spectrum of EV charging technologies, from low-power workplace charging to high-power fast charging with energy storage. The dual-site setup enables cross-comparison of multi-brand interoperability, flexibility delivery, and AI-based optimization strategies under common monitoring and control conditions.

Through their integration with SYSLAB, both sites contribute to the development of future-ready EV charging architectures, demonstrating how distributed intelligence, renewable integration, and constrained-grid operation can coexist in a coordinated framework that supports grid stability, user needs, and decarbonization goals.

1.3 Structure

The remainder of this deliverable is organized as follows. Section 2 presents an overview of the defined use cases, as well as detailed test case specifications for both slow and fast charging demonstrations, including roles and responsibilities. Section 3 outlines the scope, objectives and site assets of both demonstrators, followed by the development plan, standards, installation layout, and testing criteria. Section 4 describes the test framework, required data structure, and the intermediate states of the envisioned energy management system over the course of the roll-out. Section 5 defines a framework of KPIs, and details which KPIs are applicable to which of the two demonstration sites. Section 6 summarizes the main outcomes and next steps.

2 FINAL SPECIFICATIONS FOR THE USE CASES

AHEAD Demonstration Use Cases and Test Case Specifications for Multi-Brand Slow and Fast Charging

2.1 Methodological Approach

All experiments follow a consistent testing workflow:

- Definition of use-case scenarios (UC1–UC12) and mapping to technical test cases.
- Real-time execution of control signals
- Continuous monitoring of power, energy, and communication data.
- Evaluation of key performance indicators (responsiveness, tracking error, availability, flexibility potential, and user acceptance).

2.2 Use Cases Overview

Table 1 provides an overview of all use cases considered in Task 7.1.

Table 1 Overview of UC1 – UC12

UC NR.	USE CASE	OBJECTIVE	EXPECTED OUTCOME
UC1	NEW DR AND FLEXIBILITY CONTRACTS	Test new demand response (DR) programs tailored for e-mobility mass adoption and evaluate user acceptance of AI-based flexibility tools.	- Validated DR contract models for EV flexibility - Demonstrated user acceptance of AI tools - Quantified flexibility potential under new contract types
UC2	CHARGING STATIONS WITH LOW RATED CAPACITY	Demonstrate smart power management under limited grid capacity.	- Validated load balancing and prioritization algorithms - Increased utilization efficiency of low-capacity stations - Demonstrated energy buffering benefits
UC3	CYBER-SECURE CHARGING PLATFORM	Validate secure communication between EVs, EVSE, and backend using OCPP 2.0.1 and WP5 cybersecurity tools.	- Demonstrated secure end-to-end charging process - Enhanced privacy and authentication mechanisms - Validated WP5 cybersecurity framework
UC5	SMART CHARGING IN WORKPLACES	Optimize charging through distributed and centralized flexibility control integrated with RES and dynamic tariffs.	- Quantified impact of dynamic pricing on utilization - Evaluated flexibility coordination approaches - Improved RES self-consumption at workplace sites
UC7	SMART CHARGING ON HIGHWAYS	Demonstrate coordinated hybrid buffered fast charging for highway locations and analyze price–utilization correlation.	- Demonstrated optimal price models for utilization - Validated hybrid buffered fast charging efficiency - Identified LV grid mitigation strategies
UC9	COORDINATED CHARGING VIA CPOS	Test AI-informed user engagement and multi-vendor aggregation for flexibility delivery.	- Demonstrated user participation in AI-guided charging - Verified interoperability across brands - Quantified aggregate flexibility potential
UC10	COORDINATED CHARGING IN A VPP SETUP	Demonstrate integration of chargers, RES, and BESS into a virtual power plant for DSO flexibility services.	- Operational VPP demonstration - Validated aggregated flexibility delivery - Enhanced coordination between assets
UC11	ACTIVATION OF FLEXIBILITY	Demonstrate real-time flexibility activation via data	- Proven framework for DSO-triggered flexibility

	SERVICES BY DSOS	exchange between DSOs and CPOs.	- Evaluated AI-based dispatch responsiveness - Improved grid support coordination
UC12	GRID PLANNING WITH AI TOOLS	Validate AI-based models for predicting and planning EV charging impacts on grids.	- Validated AI grid planning tools - Enhanced prediction of charging-driven congestion - Decision-support models for DSOs and planners

2.3 Detailed Test Case Specifications

Based on the Use Cases defined in WP1 (Scenario and Use Case Formulation), the Test Cases developed under WP7.1 provide the practical validation framework for the Nordic demonstration. Each test case directly translates the conceptual and technological objectives of the AHEAD use cases, such as demand response, cybersecurity, flexibility activation, renewable integration, and AI-based grid support-into measurable experiments carried out at the demonstration sites.

TEST CASE SPECIFICATIONS - Slow Charging Demonstration

Table 2 provides an overview of the test cases considered at the slow charging demonstration on DTU Risø Campus. The remainder of the section provides per test case a list of corresponding use cases, a short description, and a list of objectives.

Table 2 Overview of test cases for the Nordic slow charging demonstration.

TC1	Dynamic Enforcement of Site-Level Power Limits
TC2	Responsiveness & Reliability
TC3	User Acceptance During DR
TC4	DR Strategy Impact
TC5	Optimized Load Utilization
TC6	Optimal vs Heuristic Energy management
TC7	Cybersecurity Assessment
TC8	Distributed vs Centralized
TC9	PV/WIND Priority Charging
TC10	Dynamic Pricing Impact
TC11	AI-Informed Coordinated Charging
TC12	Coordinated Flexibility Activation in VPP
TC13	Grid/Environmental Benefits
TC14	Real-Time Flexibility Provision via CPO-Controlled EV Charging

TC15	AI Grid Impact Prediction

Test Case 1: Dynamic Enforcement of Site-Level Power Limits via OCPP	
Link to Use Case	UC1
Description:	Dynamically control total site power consumption by sending charging profiles to individual EV chargers through a centralized backend using OCPP 1.6 communication. Enforce site-level power limits dynamically by dispatching commands to individual chargers connected via Spirii backend using OCPP 1.6 JSON over WebSocket.
Objective:	1. Demonstrate coordinated load control across multiple chargers to maintain total site power within a dynamic limit. 2. Assess the ability of the backend to distribute and update charging power among chargers in real time. 3. Evaluate the stability and fairness of the power allocation strategy.

Test Case 2: Responsiveness and Reliability of Multi-Brand Chargers for Flexibility Activation	
Link to Use Case	UC1
Description:	Assess the responsiveness and reliability of different brands under OCPP 1.6 for flexibility activation during peak or grid-stressed periods.
Objective:	1. Evaluate how quickly and consistently chargers from different brands react to remote control actions. 2. Assess the reliability of command execution and the frequency of failed or delayed responses. 3. Identify charger-specific differences that affect flexibility activation potential.

Test Case 3: User Acceptance and Charging Behavior During DR Events	
Link to Use Case	UC1
Description:	Assess employee user acceptance and charging behavior changes when DR programs are applied during workplace charging. Assess how employees adapt charging behavior when DR programs are applied during workplace charging (e.g., delayed charging, throttled power, or controlled start/stop). Collect user feedback on perceived impact, acceptance, and willingness to participate in DR programs.

Objective:	1. Understand how dynamic control actions (e.g., delayed or reduced charging) affect user behavior and satisfaction. 2. Measure changes in charging patterns and participation rates during demand response periods. 3. Collect user feedback to evaluate acceptance and identify potential improvements in user communication.

Test Case 4: DR Strategy Impact	
Link to Use Case	UC1
Description:	Demonstrate and measure the effects of different DR strategies (power throttling, load shifting, scheduled interruptions) on user charging sessions: - Monitor delays in session completion. - Assess user comfort and dissatisfaction reports. - - Evaluate potential for user opt-out.
Objective:	1. Quantify how different DR strategies (throttling, shifting, scheduled interruptions) influence site performance and user experience. 2. Compare their effectiveness in reducing peak loads and integrating renewable generation. 3. Identify the most suitable strategy for balancing grid support and user convenience.

Test Case 5: Optimized Load Utilization	
Link to Use Case	UC2
Description:	Demonstrate control strategies that maximize charging utilization while respecting site power constraints, ensuring fair distribution among users, and maintaining high user acceptance under realistic utilization and user behavior patterns.
Objective:	1. Demonstrate control strategies that maximize total charging energy delivery within site power and grid constraints. 2. Ensure fair and efficient power distribution among users based on arrival time, session duration, or user priority. 3. Maintain user satisfaction while optimizing utilization under realistic usage patterns.

Test Case 6: Optimal vs Heuristic Energy management	
Link to Use Case	UC2

Description:	Compare scheduling vs. modulation control for grid-constrained EV charging in terms of: - Grid constrains compliance and flexibility potential. - Impact on user experience (completion rates, wait times). - PV and RES utilization potential. - Operational complexity and scalability in multi-brand, multi-site contexts.
Objective:	1. Compare the performance of optimization-based (e.g., scheduling) and rule-based (heuristic) energy management approaches. 2. Assess each method's impact on grid constraint compliance, flexibility potential, and renewable energy utilization. 3. Evaluate differences in user experience (charging completion rate, waiting time) and operational scalability across brands and sites.

Test Case 7: Cybersecurity Assessment	
Link to Use Case	UC3
Description:	Assess security vulnerabilities of multi-brand OCPP 1.6 slow chargers under real deployment conditions in public networks. Evaluate impacts on operational functions: session initiation, SetChargingProfile commands, heartbeat consistency, and flexibility activation.
Objective:	1. Assess cybersecurity vulnerabilities and resilience of multi-brand OCPP 1.6 slow chargers under real deployment conditions. 2. Evaluate how security threats or network disruptions impact normal operations (session initiation, charging profile updates, heartbeats, and flexibility activation). 3. Identify weak points in authentication, message integrity, and communication stability across brands. 4. Develop recommendations for secure configuration, monitoring, and mitigation strategies.

Test Case 8: Distributed vs. Centralized Control Strategies for Workplace EV Charging	
Link to Use Case	UC5
Description:	Demonstrate and compare distributed control (e.g., local charger fallback logic) vs. centralized control (SPIRII backend) for workplace EV charging under real grid-constrained conditions. Quantify:

	- Available flexibility potential (kW) that each approach can deliver for demand response. - Responsiveness to grid signals (ramp rates, time delay to adjust charging). - Impact on user charging completeness (sessions finished as planned) and additional wait times.
Objective:	1. Compare distributed (local) vs centralized (backend) control in grid-constrained conditions. 2. Evaluate responsiveness to grid signals and available flexibility. 3. Assess user impact in terms of session completion and waiting time.

Test Case 9: PV/WIND-Priority Control in Workplace Charging	
Link to Use Case	UC5
Description:	Develop and evaluate PV/WIND-priority control strategies for workplace EV charging with slow chargers to maximize PV/WIND self-consumption. Quantify: - Increase in RES utilization ratio (% of PV/WIND used locally). - Impact on user experience (session completion, delays). - Interaction with site power constraints and grid import minimization. Demonstrate feasibility in real-world, multi-brand OCPP 1.6 environments.
Objective:	1. Develop and validate renewable priority control strategies for EV charging. 2. Maximize local PV/WIND utilization while maintaining user satisfaction. 3. Evaluate interaction with grid import and site limits.

Test Case 10: Dynamic Pricing Impact	
Link to Use Case	UC5
Description:	Demonstrate how dynamic pricing (e.g., time-of-use, real-time, or critical peak pricing) shifts user charging patterns in a workplace setting. Quantify: - Changes in user plug-in times and session durations in response to price signals. - User acceptance of delayed or throttled charging when incentivized by lower prices. - Net effect on total user energy costs and PV utilization at the site. - Identify which pricing structures are most effective at shifting behavior while preserving user satisfaction.
Objective:	1. Assess how dynamic pricing influences charging behavior and load distribution. 2. Quantify effects on user participation, cost savings, and PV utilization. 3. Identify pricing models that shift demand while keeping users satisfied.

Test Case 11: AI-Informed Coordinated Charging via CPOs with Multi-Vendor Aggregation	
Link to Use Case	UC9
Description:	Test how users respond to AI-informed suggestions for optimal charging time slots, aiming to shift charging away from peak grid hours or toward higher renewable availability. Demonstrate real-time flexibility provision using CPO-controlled multi-brand slow EV chargers under operational conditions in the field.
Objective:	1. Evaluate user response to AI-generated charging recommendations that avoid grid peaks and follow renewable availability. 2. Demonstrate coordinated flexibility delivery across multi-brand chargers under real-world operation. 3. Assess potential for AI to improve site-level efficiency and user participation in flexibility programs.

Test Case 12: Coordinated Flexibility Activation in VPP	
Link to Use Case	UC10
Description:	Develop and demonstrate methods for integrating multi-brand slow chargers into Virtual Power Plant (VPP) operations to deliver grid flexibility services under real conditions. Quantify flexibility potential, including up/down modulation capacity and ramp rates: - Measure responsiveness to VPP dispatch signals under Spirii control. - Assess impact on user experience and charging completeness during flexibility activations. - Identify operational challenges and propose scalable solutions for VPP–CPO integration across brands.
Objective:	1. Demonstrate multi-brand charger integration into a Virtual Power Plant (VPP). 2. Quantify flexibility potential (up/down modulation, ramp rates). 3. Evaluate response to VPP dispatch and user impact during activations. 4. Identify challenges and scalable solutions for VPP–CPO coordination.

Test Case 13: Grid and Environmental Benefits of VPP-Integrated EV Charging	
Link to Use Case	UC10
Description:	Evaluate grid and environmental benefits of integrating EV charging into VPP operations under real workplace/public deployments.

	Quantify grid benefits: - Peak demand reduction during VPP activation. - Contributions to voltage and frequency stability. - Support for congestion management. Quantify environmental benefits: - Increased PV/wind self-consumption through flexible charging. - Reduced CO_2 emissions by shifting loads to low-carbon periods. - - Avoided curtailment of renewable generation.
Objective:	1. Quantify grid and environmental benefits from VPP-integrated EV charging. 2. Evaluate peak reduction, voltage stability, and congestion support. 3. Assess renewable utilization and CO_2 reduction through flexible charging.

Test Case 14: Real-Time Flexibility Provision via CPO-Controlled EV Charging	
Link to Use Case	UC11
Description:	Develop and demonstrate a practical framework for real-time flexibility activation using multi-brand OCPP 1.6 slow chargers in operational environments under Spirii control. Quantify: - Flexibility volumes delivered (kW, duration) during DSO-triggered events. - Response times and ramp rates under DSO requests. - Impact on user sessions and satisfaction (session completion, delays, complaints).
Objective:	1. Demonstrate real-time flexibility activation through CPO-controlled chargers. 2. Quantify delivered flexibility volumes and response performance under DSO-triggered events. 3. Assess user experience during real-time control (session completion, delays, satisfaction).

Test Case 15: AI Grid Impact Prediction	
Link to Use Case	UC12
Description:	Develop an AI-based predictive model to forecast grid impacts of EV charging integration at the distribution network level. Quantify: - Voltage deviations, loading impacts, and congestion likelihood under varying charging patterns. - Prediction accuracy compared to traditional methods.

Objective:	1. Develop and test an AI-based model predicting grid impacts from EV charging. 2. Quantify accuracy against traditional analytical or deterministic methods. 3. Assess predictive capability for voltage deviations, load congestion, and network stress.

TEST CASE SPECIFICATIONS - Fast Charging Demonstration

Table 3 provides an overview of the test cases considered at the fast charging demonstration on DTU Risø Campus. The remainder of the section provides per test case a list of corresponding use cases, a short description, and a list of objectives.

Table 3 Overview of test cases for the Nordic fast charging demonstration.

TC1	Flexibility Activation During Grid Peak Load
TC2	Frequency Regulation with BESS
TC3	Coordination Between DSO and TSO
TC4	Cybersecurity assesment
TC5	Smart Power Allocation Under Peak Load
TC6	RES Curtailment Avoidance at High Production
TC7	Dynamic Pricing Impact
TC8	Real-time flexibility provision via CPO
TC9	Emergency Grid Outage Management
TC10	Optimal vs. Heuristic Energy Management
TC11	Coordinated Flexibility Activation in VPP
TC12	Grid/enviromental benefits
TC13	AI grid impact predictions

Test Case 1-Flexibility Activation During Grid Peak Load	
Related Use Case	UC1
Description	During a scheduled or real-time DSO-triggered flexibility event, the EV charging station must cap or reduce its grid power draw to a pre-defined threshold (e.g., from 43 kW to 10 kW) for a specific duration (e.g., 30–60 minutes) . The charging station must compensate for the grid shortfall by intelligently using its battery buffer (BESS) and renewable generation (e.g., PV) to continue delivering energy to EVs. Multiple charging sessions may be active during this time, requiring:

	- Prioritization or load balancing, - Adaptive BESS discharge control, - Integration with smart energy management systems (EMS) to stay within constraints. After the flexibility event ends, the system can return to normal operation. The test will log the response time, grid power limitation performance, SoC impact, and overall user satisfaction
Objective	1. To evaluate the ability of a hybrid EV fast-charging system (with BESS and RES integration) to respond to a real-time flexibility request from a DSO, limiting its grid consumption during a defined high-load period. The test aims to demonstrate that the system can: - Meet the flexibility commitment (e.g., limit grid power draw to ≤5 kW), - Maintain EV charging services using local resources (BESS/RES), - Avoid negative impacts on user experience (SoC, delays),

Test Case 2-Frequency Regulation with BESS	
Related Use Case	UC1
Description	During the test, simulated frequency deviations (e.g., dips below 49.9 Hz or rises above 50.1 Hz) will be injected into the local energy management system, emulating a request from the Transmission System Operator (TSO) for automatic frequency response. The BESS should react by either: - Discharging (injecting power) during frequency drops (under-frequency), - Charging (absorbing power) during frequency spikes (over-frequency), - all while coordinating with any active EV charging sessions at the site. The test assesses: - Speed and accuracy of BESS response. - Priority handling between EV charging and grid support. - Control algorithm stability, - Impact on user experience and SoC targets.
Objective	1. To evaluate the ability of the Battery Energy Storage System (BESS) within a fast-charging station to participate in frequency regulation services by responding to real-time frequency deviations (e.g., primary reserve/FCR-D) in coordination with grid requirements, without compromising ongoing EV charging sessions. 2. This test aims to demonstrate:

	- Technical feasibility of using BESS for frequency control. - Ability to maintain charging quality during regulation. - Revenue potential or value creation from grid services.

Test Case 3-Coordination Between DSO and TSO	
Related Use Case	UC1
Description	In this test, the fast-charging site-equipped with grid connection, BESS, and RES-receives two overlapping flexibility requests: - From the DSO: reduce grid import to mitigate local congestion (e.g., 10 kW max for 30 min). - From the TSO: respond to a frequency deviation by charging or discharging BESS. - The EMS must assess: - Which signal to prioritize based on contractual rules or grid criticality. - Whether it can partially fulfill both (e.g., supply TSO service while staying within DSO constraint). - How this affects EV charging performance. This test reflects a real-world scenario in future flexible markets, where local and system-wide grid needs must be balanced.
Objective	1. To evaluate how the local energy management system at a fast-charging site handles simultaneous or conflicting flexibility requests from both a DSO (e.g., voltage constraint or local congestion) and a TSO (e.g., frequency regulation or balancing reserve). 2. The goal is to test prioritization logic, operational feasibility, and the ability to satisfy one or both requests without violating system or user constraints.

Test Case 4-Cybersecurity assesment	
Related Use Case	UC3
Description	This test conducts a vulnerability assessment of an EV charging station running OCPP 2.0.1, identifying insecure channels, weak authentication, and open ports. It simulates known threat vectors to detect potential cybersecurity risks in legacy infrastructure.
Objective	1. Identify exploitable weaknesses in legacy OCPP 2.0.1 communication

Test Case 5-Smart Power Allocation Under Peak Load	
Related Use Case	UC2
Description	Test how the system dynamically distributes limited grid, RES, and battery power when multiple EVs charge at once, ensuring charging performance without overloading the grid.
Objective	1. Validate energy allocation logic when multiple EVs arrive simultaneously.

Test Case 6-RES Curtailment Avoidance at High Production	
Related Use Case	UC2, UC7
Description	This test ensures that the system maximizes the use of locally produced renewable energy (e.g., PV) by directing it toward EV charging or battery storage when production exceeds local demand, minimizing curtailment.
Objective	1. Assess system's ability to absorb excess RES when grid and EV demand are low.

Test Case 7-Dynamic Pricing Impact	
Related Use Case	UC7
Description	This test evaluates how EV users respond to dynamic charging prices at a fast-charging station. Price signals (e.g., time-of-use or real-time pricing) are shown to users before charging, and their acceptance, delay tolerance, or rejection behavior is recorded.
Objective	1. Measure sensitivity of EV users to pricing signals 2. Understand trade-offs between charging speed, timing, and cost. Support pricing strategies to shift load toward grid-friendly periods

Test Case 8-Real-time flexibility provision via CPO	
Related Use Case	UC7
Description	This test validates the ability of a fast-charging site to provide on-demand flexibility to a DSO during congestion periods or local voltage issues, using BESS and EMS to reduce grid usage temporarily.

Objective	1. Demonstrate controlled grid import reduction on DSO request 2. Maintain service using BESS 3. Evaluate feasibility of station-based DSO flexibility markets

Test Case 9-Emergency Grid Outage Management	
Related Use Case	UC2
Description	This test simulates a grid outage during an active EV charging session. The system must detect the outage and maintain service using BESS, while safely managing EV charging profiles until the grid is restored.
Objective	1. Validate backup capabilities of BESS and EMS 2. Ensure user safety and session continuity 3. Test system restoration behavior after grid recovery

Test Case 10-Optimal vs. Heuristic Energy Management	
Related Use Case	UC1,UC2,UC7
Description	This test compares two energy management strategies for operating a fast-charging station equipped with BESS and RES: (1) a heuristic rule-based approach and (2) an optimization-based approach. Both strategies aim to meet user SoC targets while minimizing grid stress and cost. The test quantifies performance differences under identical load and weather conditions.
Objective	1. Quantify cost savings and RES utilization improvement using optimization 2. Evaluate impact on user experience (charging time and SoC delivery) 3. Compare grid usage patterns and battery cycling under both strategies

Test Case 11-Coordinated Flexibility Activation in VPP	
Related Use Case	UC10
Description	This test case verifies the capability of the virtual power plant (VPP) composed of the fast charging installation and slow charging installation at Risø campus to collectively activate and provide grid flexibility services. The VPP should coordinate the charging loads of both installations and leverage the battery energy storage system (BESS) and renewable energy sources (RES) to respond dynamically to grid signals or market requests, thus contributing to grid stability and optimization.

Objective	1. Demonstrate coordinated control of fast and slow chargers under the VPP framework to provide flexibility services. 2. Validate the ability to modulate EV charging loads in response to grid operator requests. 3. Confirm that the BESS and RES are optimally integrated into the VPP to support load shifting or peak shaving. 4. Ensure communication and control infrastructure properly enable real-time dispatch of flexibility signals.

Test Case 12-Grid/environmental benefits	
Related Use Case	UC1
Description	This test evaluates how a smart charging strategy can reduce CO_2 emissions by scheduling EV charging during low-carbon intensity periods (e.g., high RES production, low marginal grid emissions). The energy management system prioritizes low-emission time slots using real-time or forecasted grid CO_2 intensity data. The test compares total CO_2 emissions per session between standard charging and optimized charging.
Objective	1. Quantify reduction in CO_2 emissions from smart charging 2. Demonstrate integration of real-time carbon intensity signals into EMS 3. Evaluate trade-offs between emissions, cost, and user flexibility

Test Case 13-AI grid impact predictions	
Related Use Case	UC12
Description	This test ensures that the data collected from the EV charging station is complete, accurate, and relevant for low-voltage (LV) grid planning. It focuses on monitoring session-level demand profiles, peak usage windows, power quality metrics (if available), and usage trends to support grid reinforcement or flexibility planning.
Objective	1. Validate charging data for completeness and resolution. Collect usage data to train AI models. 2. Identify peak load periods and charging clusters over time and location. 3. Input data into CIM or pandapower grid models for planning.

2.4 Roles and Responsibilities

Table 4

Table 5The roles and responsibilities of the project partners involved in the Nordic slow-charging and fast-charging demonstrations are presented in Table 4 and Table 5, respectively. The test cases specified for each partner represent the ones where they hold the main responsibility (first point of contact). However, all partners will be involved in the execution of all test cases.

Table 4 Roles and Responsibilities for the slow charging demo.

Partner	Role	Related TC
DTU	System design, control validation, KPI and algorithm analysis, simulation and AI model support.	TC4, TC6, TC9, TC
SPIRII	Backend operation, charging platform management, dynamic load control, flexibility orchestration, cybersecurity integration.	TC1, TC5, TC7, TC11, TC12, TC14
AMINA	Charger manufacturer responsible for hardware tests, local fallback logic, cybersecurity verification, and compatibility in flexibility scenarios.	TC2, TC8
RUC	Socio-technical research, user acceptance evaluation, behavioral analysis, and predictive modeling for flexibility and pricing.	TC3, TC15
ELBIL	EV driver engagement, user recruitment, behavioral data collection, and CO_2/environmental impact evaluation.	TC10, TC13

Table 5 Roles and responsibilities for the fast charging demo.

Partner	Role	Related TC
DTU	System design, control validation, KPI and algorithm analysis, simulation and AI model support.	TC2, TC5, TC6, TC10
KEMPOWER	Fast-charger manufacturer providing hardware, OCPP integration support, dynamic power control capabilities, and operational assistance for the fast-charging demonstration.	TC1, TC3, TC9
SPIRII	Backend operation, charging platform management, dynamic load control, flexibility orchestration, cybersecurity integration.	TC4, TC8, TC11
ELBIL	EV driver engagement, user recruitment, behavioral data collection, and CO_2/environmental impact evaluation.	TC7, TC12

RUC	Socio-technical research, user acceptance evaluation, behavioral analysis, and predictive modeling for flexibility and pricing.	TC13

3 PLANS FOR DEVELOPMENT, INSTALLATION AND COMMISSIONING

3.1 Scope & Objectives

This chapter translates the test-case into a concrete plan to develop, install, and commission the multi-brand slow-charging & fast-charging demonstration at DTU-Risø. It covers design principles, installation layout, electrical and communications architecture, backend integration (Spirii), testing & acceptance criteria.

Primary goals

- Deliver a safe, standards-compliant slow-charging cluster that operates under a site power cap while coordinating with local PV and wind resources.
- Prove multi-brand interoperability (Amina, Fronius, Zaptec) for flexibility and DR via OCPP-based control, integrated with SYSLAB monitoring.
- Demonstrate coordinated operation of the Kempower DC fast-charging system and Pixii battery storage (BESS) for flexibility and demand response services, integrated with SYSLAB's real-time monitoring and energy management platform.
- Establish a repeatable commissioning & KPI baseline that feeds all Test Cases (TC1–TC15) and creates a scalable blueprint for other sites.

3.2 Site & Assets (Summary)

- Location: DTU-Risø campus
- Chargers (slow AC & fast Chrgers): Multi-brand mix (Amina, Fronius, Zaptec, EV4EU chargers ect,.) & Kempower.
- Battery: Pixii BESS.
- Local generation: PV ~30 kW + wind ~22 kW (behind-the-meter), integrated for RES-priority charging experiments.
- Backend/CSMS: Spirii (OCPP 1.6J over WebSocket)

3.3 Development Plan & Timeline

Table 6 Development plan and timeline

Phase & Title	Timeframe
Phase A – Design	Sep- mid Oct 2025

Phase B – Procurement & Prep	Oct–Nov 2025
Phase C – Civil/MEP Works	mid-Nov 2025 – Feb 2026
Phase D – Energization & Commissioning	Mar – mid-Apr 2026
Phase E – Safety file/as-built pack delivery; operator training	mid-Apr – May 2026
Phase F - Test case development	2025-2026-2027

3.4 Electrical & Mechanical Standards, Communication Protocols, and System Concept

Electrical & Mechanical Standards

- IEC 61851-1 – Electric vehicle conductive charging system (EVSE).
- IEC 60364-7-722 – Requirements for EV installations (protection, circuits, RCD).
- IEC 61439-1/-2 – Low-voltage switchgear & control gear assemblies.
- IEC 60364-4-41 / -5-54 – Protection against electric shock; earthing & bonding.
- IEC 60529 – IP ratings (enclosures, e.g., IP54+ outdoors).
- IEC 61000-6-2 / -6-4 – EMC immunity/emission (industrial environments).
- EN 12464-2 (site lighting) & ISO 7010 (safety signage) – as applicable.
- RCD policy: Type A + 6 mA DC detection in EVSE (or Type B where required).

Communication Protocols

- OCPP 1.6J/2.01J over WebSocket/WSS (TLS 1.2+), JSON payloads.
- Authentication: device certificates or shared secrets (per CSMS policy).
- Networking: IPv4, VLAN segregation for EVSE; optional site VPN to CSMS.
- Management/ops (as needed): DHCP, DNS; syslog/SIEM for security monitoring.

System Concept

A multi-brand cluster of slow AC chargers (e.g., Amina, Fronius, Zaptec) communicates via OCPP 1.6J with the Spirii backend for centralized control. The charging infrastructure is integrated with DTU's SYSLAB, where local RES (PV & wind) signals and measurements are available so charging can prioritize renewables and respect a site power cap. In parallel, a fast-charging site integrates a KEMPOWER DC charging system with a Pixii battery energy storage system (BESS) and local PV generation to deliver up to 150 kW of charging under a limited 22 kW grid connection, demonstrating hybrid operation, flexibility activation, and grid-supportive control.

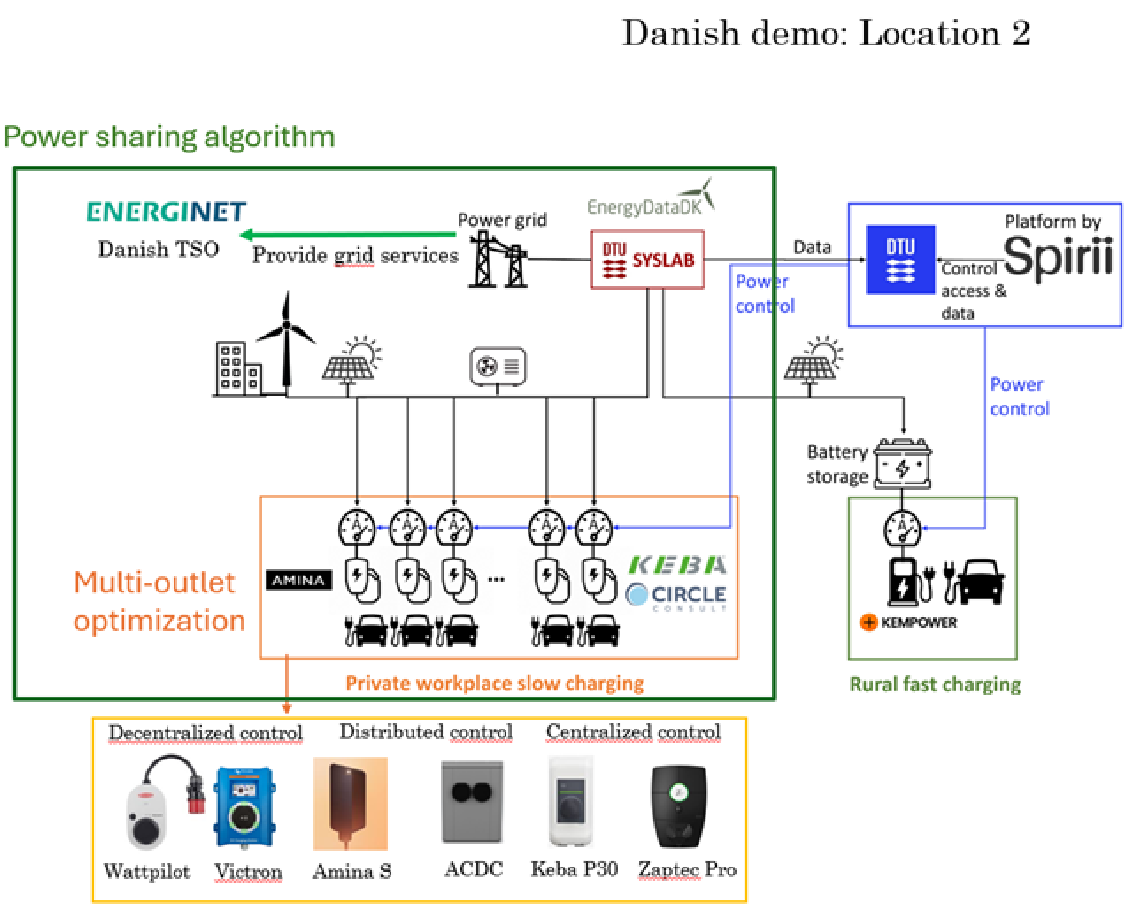

Figure 1 Schematic of the Nordic demo sites.

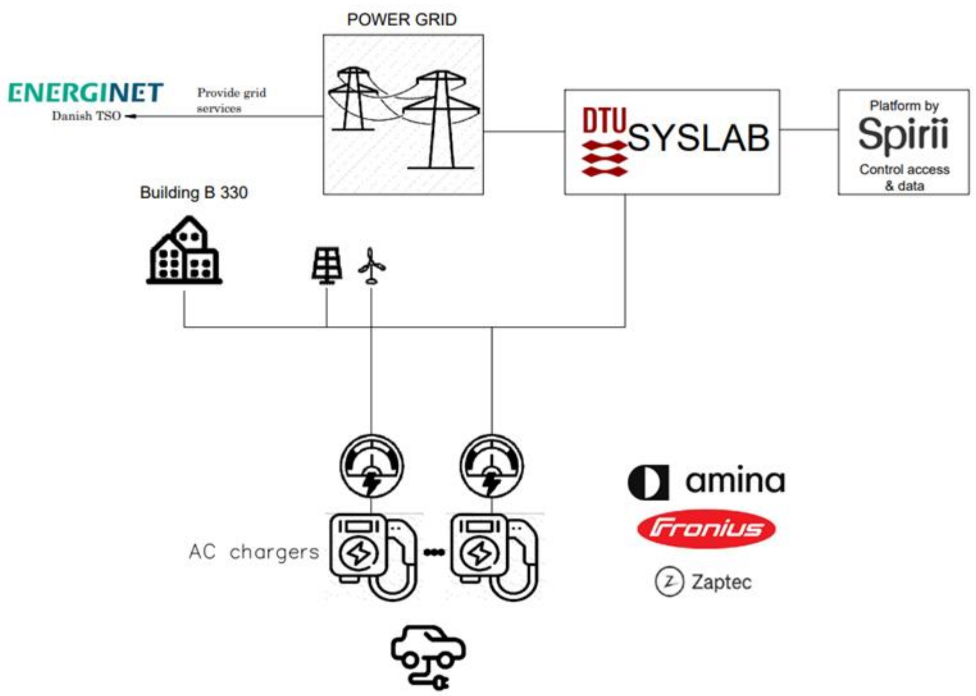

Figure 2 Schematic of the slow charging demonstration.

3.5 Installation Layout

Slow Charging

The slow-charging installation has been designed to demonstrate advanced management and interoperability concepts for multi-brand AC chargers operating under realistic conditions. The layout includes several 22 kW charging units from different manufacturers, all interconnected through Spirii's OCPP backend to ensure a unified and vendor-agnostic control environment.

The chargers are supplied from a shared low-voltage distribution board with an intentionally limited site capacity of about 43 kW, enabling the testing of dynamic load management, demand-response, and AI-based coordination strategies. The installation layout allows flexible electrical grouping, clear labelling of feeders and protection devices, and seamless data communication with the central CSMS. This configuration provides the necessary observability and control granularity for assessing interoperability, performance, and flexibility delivery across different charger brands.

- EVSE-15 (32 A) - Amina × 3 (3×16 A)
  Baseline/control - Used to compare distributed control (local Amina fallback logic) vs centralized control via Spirii (OCPP 1.6J) under identical physical conditions.
- EVSE-16 (32 A) - Amina × 2 (2×16 A) + Zaptec Pro × 1 (16 A)
  Cloud-latency - Evaluates the impact of Zaptec cloud backhaul and data granularity on sharing and tracking when coordinated through Spirii.

Figure 3 Cluster layout slow charging demonstration.

- EVSE-13 (32 A) - Amina × 2 (2×16 A) + Fronius × 1 (16 A)

Mixed-brand - Assesses fairness, ramp response, and compliance across different vendors under identical profiles and power-cap conditions.

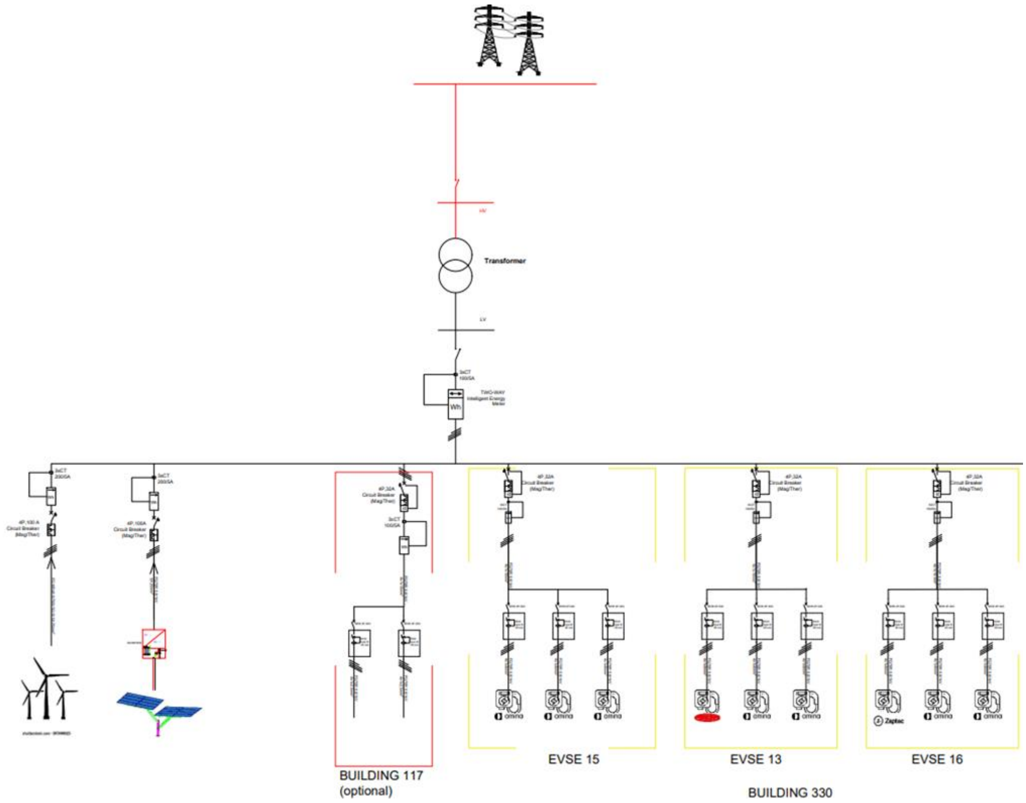

Figure 4 Cable layout slow charging demonstration.

Fast Charging

The fast-charging installation has been designed to showcase advanced power management, battery-buffered operation, and grid-support capabilities for high-power DC charging systems. This setup simulates a realistic fast-charging hub scenario by integrating multiple energy sources and implementing control strategies for peak shaving, load optimization, and reduction of grid congestion.

The configuration includes:

- 150 kW DC KEMPOWER charger.
- 325 kWh BESS from PIXII.
- 43 kW grid connection.
- 30 kW of RES connection.

These components are coordinated through an EMS that dynamically allocates power between the grid, the BESS, the RES, and connected electric vehicles based on charging demand, the state of charge, and grid constraints. This enables continuous assessment of system flexibility, control reliability, and communication interoperability among the charger, battery, and backend systems.

Extensive monitoring at the DC link and grid interface provides high-resolution data for model validation and algorithm tuning, while OCPP-based control ensures vendor-neutral interoperability.

Figure 5 Cable routing for the grid connection of the fast charging demo site.

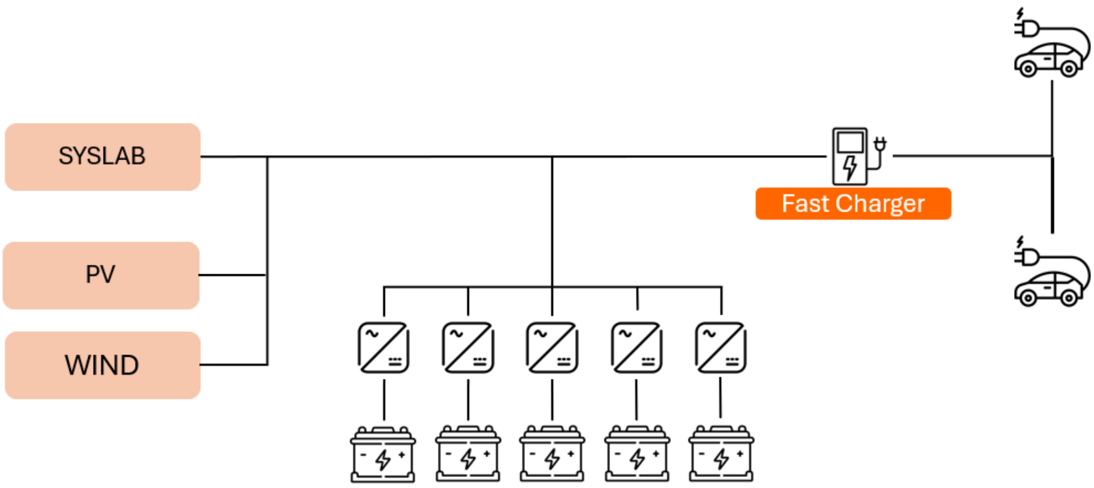

Figure 6 Setup of the fast charging demonstration.

3.6 Testing & Acceptance Criteria

Table 7 Testing and acceptance criteria.

Test area	Procedure (summary)	Metric(s)	Acceptance
Safety & Power	IR, earth continuity, loop impedance, polarity, RCD trip, phase rotation	Pass/Fail per IEC 60364/61851; RCD trips within spec	All tests pass and recorded
OCPP Core	BootNotification→Heartbeat →Status; Start/StopTransaction	Message sequence, IDs match	100% sequence success; IDs consistent with labels
MeterValues Cadence	Observe periodic + event MeterValues	Interval, units	≤ 30-60 s interval; units consistent
Failover & Recovery	Block CSMS link; restore	Local fallback behavior; auto-resume time	Safe fallback observed; auto-resume ≤ 60 s after link returns
Cybersecurity (basic)	Verify EV-VLAN, default-deny inbound, TLS/WSS where supported, creds vault	Config state	Segregation active; TLS on Amina/Fronius; Zaptec via cloud; creds stored

4 DATA MONITORING AND ACQUISITION

The system configuration is as in Figure 7, with 3 clusters providing different combinations between the hardware – Amina C, Zaptec Pro and Fronius - and Spirii backend as CPMS system solution.

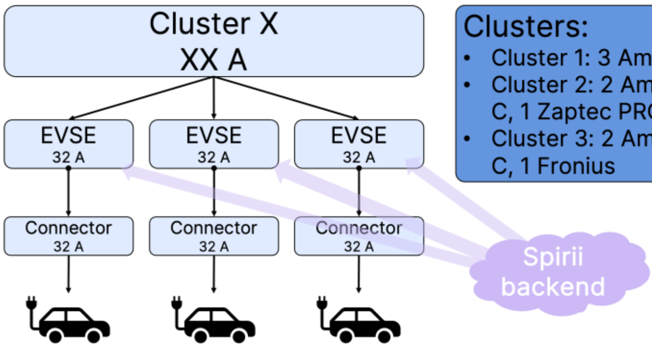

Figure 7 System configuration and clusters.

To efficiently utilize the available circuit capacity, the Dynamic Load Management (DLM) feature implemented by Spirii can be utilized. This can be enabled/disabled, depending on the needs of the location and the tests investigated.

A DLM is a real-time allocation of a site's available electrical capacity across EV charge points. Instead of letting each charger draw its maximum independently, the DLM redistributes power so all connected vehicles can charge without tripping fuses or exceeding site limits. This protects infrastructure, improves fairness across chargers, and makes better use of the power available.

There are different strategies for capacity allocation for different use cases and charging efficiency. Currently, the considered DLM for the project can distribute the available capacity across the actively charging connectors accounting for the individual max current limitations of the given connector. When the DLM balancing logic is active, the circuit will be rebalanced based on the following events:

1. Connector status changes
2. Circuit update
3. A chargebox is added to the circuit
4. A chargebox is removed from the circuit
5. An external control is applied

In the case there is not enough capacity for all EVSEs to charge above the minimum current, connectors are prioritized depending on their arrival (start charging) time. To improve charging experience, and due to hardware limitations, a concept of minimal "floor" current is introduced. This floor current is often considered equal to 0 amps or 6 amps, but due to different hardware manufacturer implementations, configurable floors depending on hardware manufacturer constraints will be implemented.

A major prerequisite for DLM is that the charger model has to support native OCPP, charging profiles, and has passed Spirii's internal validation. Currently, of the considered chargers in the project the Amina C is supported and this will be the initial status for investigation, while Zaptec PRO and Fronius are part of current development.

A safety configuration of the DLM is that if a charger is not responsive, it is assumed to be charging at a limit from its latest relevant profile, and the available circuit capacity is adjusted accordingly to protect the fuse. In cases where the charger is not responsive or rejecting profiles, the charger is excluded from the balancing pool, and communication is checked periodically. In case of a prolonged malfunction, the NOC team and relevant stakeholders will be notified to address the issue.

4.1 Test Framework

To closely collaborate with external partners, i.e., DTU, and provide access to external partners to control chargers in real-time, Spirii is developing the so called "Test Framework". This is developed in collaboration with the R&D projects – FLOW and e2flex – and an overview of the system is displayed in Figure 8. The Test Framework is a translation layer that gives access to third parties (External) to run controlled charger tests against Spirii-managed chargers without Spirii having to operate each test manually. It can use the DLM on the backend side, as this feature can be enabled or disabled. The External partners can receive state information and set power limit to the chargers through an API request.

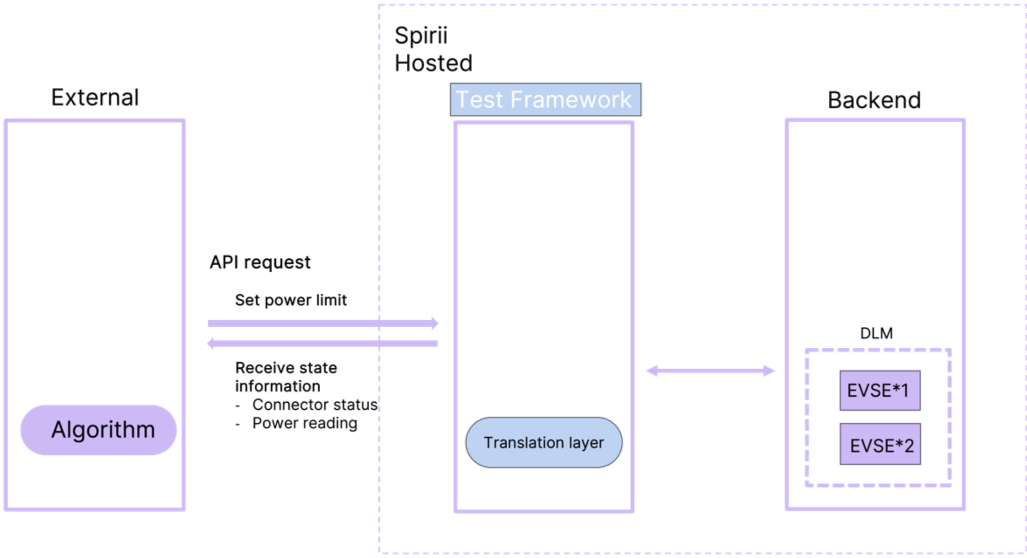

Figure 8 Testing framework overview.

As for the tests in AHEAD, DTU is the Charging Point Operator (CPO) in the Spirii CPMS platform "Connect", where data regarding the chargers are available and downloadable, as well as manageable by the CPOs. Available data goes from location and connectors, to charge detail records, payment and voucher, as well as support and operations centre. More information is available here Spirii Connect.

4.2 Data structure – AMINA CHARGER

The Amina chargers continuously collect and transmit a standardized set of operational data points defined under OCPP 1.6j, which are made accessible through the SPIRII backend for monitoring and diagnostic purposes. These parameters cover key electrical and energy performance indicators, including voltage, current, power factor, active power, grid frequency, and cumulative energy import. By tracking per-phase voltage and current (typically 220–240 V and 6–32 A, respectively), the system ensures proper grid stability and load balancing during charging sessions. Power quality is further assessed through per-phase power factor values and active power readings up to 22 kW combined. The frequency and total energy registers contribute to monitoring grid consistency and total consumption over time. Together, these data points enable SPIRII and connected users to visualise real-time power flows, identify irregularities, and optimize charging behaviour based on accurate and calibrated measurements. Further details on the supported measurands and their units can be found in the Amina OCPP data point documentation, available on the official Amina technical reference webpage [Amina Charging. (2025). *Amina OCPP 1.6j Data Point Documentation*. Retrieved from **https://delightful-tree-09e2bf503.5.azurestaticapps.net/public/ocpp**].

Category	Supported Commands / Functionality	Description
Connection & Identification	BootNotification, Heartbeat, StatusNotification	Registers with backend, keeps session alive, reports state (Available, Charging, Faulted, etc.)
Metering / Telemetry	MeterValues (Voltage, Current.Import, Power.Active.Import, Power.Factor, Frequency, Energy.Active.Import.Register)	Periodic telemetry with per-phase & total values
Transactions	StartTransaction, StopTransaction, Authorize	Start/stop charging sessions and authorization (RFID/App)
Remote Control	RemoteStartTransaction, RemoteStopTransaction, ChangeAvailability, UnlockConnector	CSMS can remotely start/stop or enable/disable charger
Smart Charging	SetChargingProfile, ClearChargingProfile	Adjust charging current limit (A) in real-time or scheduled profile
	GetCompositeSchedule	Request aggregated schedule from charger
Configuration Management	ChangeConfiguration, GetConfiguration	Read or change parameters (e.g., MeterValueSampleInterval, HeartbeatInterval)
Diagnostics / Logging	GetDiagnostics, DiagnosticsStatusNotification	Request and upload diagnostic logs
Firmware Management	UpdateFirmware, FirmwareStatusNotification	Remote firmware updates
Security / Communication	Reset, DataTransfer, secure wss:// TLS connection	Reboot, custom data, secure OCPP session
Local behaviour (fallback)	–	Continues active charging if backend disconnects; buffers data

4.3 Energy management system

Energy management system (EMS) will be delivered in three different phases. In the first phase, Pixii BESS is integrated with EMS through local MQTT communication and EMS controller will be charger controller unit inside EV charger. In the second phase, BESS is integrated with EMS through Modbus TCP and EMS controller will be a separately installed local gateway which receives external commands from a cloud service. In the third phase, it's expected that integration method remains same but the cloud service doing optimization will be Kempower ChargEye.

The first phase of EMS is presented in Figure 9. In this phase peak shaving is enabled by having charger controller inside EV charger require BESS to discharge whenever EV charging can charge with more power than what the grid can deliver. BESS will handle SoC management by itself and will charge BESS whenever there's available capacity from the grid.

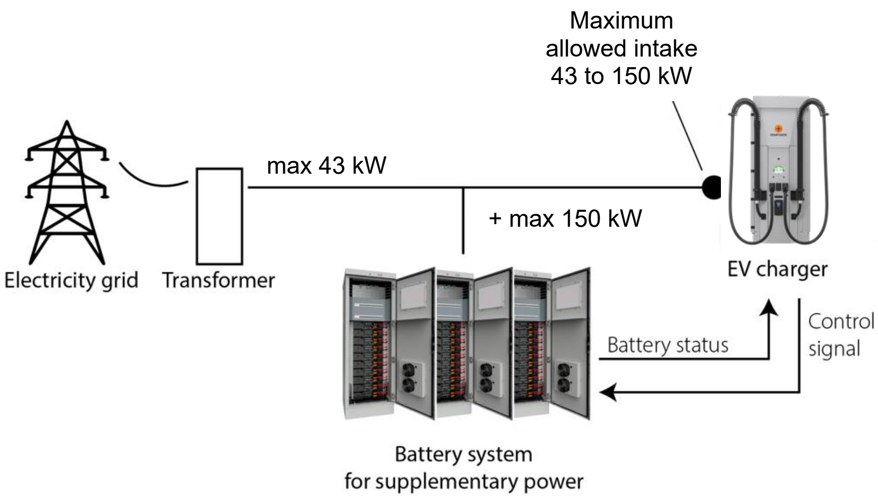

Figure 9 First phase of EMS including Kempower EV charger and Pixii BESS.

In the second phase of EMS, Figure 10, peak shaving is enabled by having a local gateway to communicate with BESS and charger through Modbus TCP and enable charger to utilize more power when BESS has activated discharging. BESS SoC management is done by the EMS cloud service so charging can be done based on the SPOT price or by the amount of local production. Optimization may be done on local level configured in the controller and cloud level configured in the cloud service.

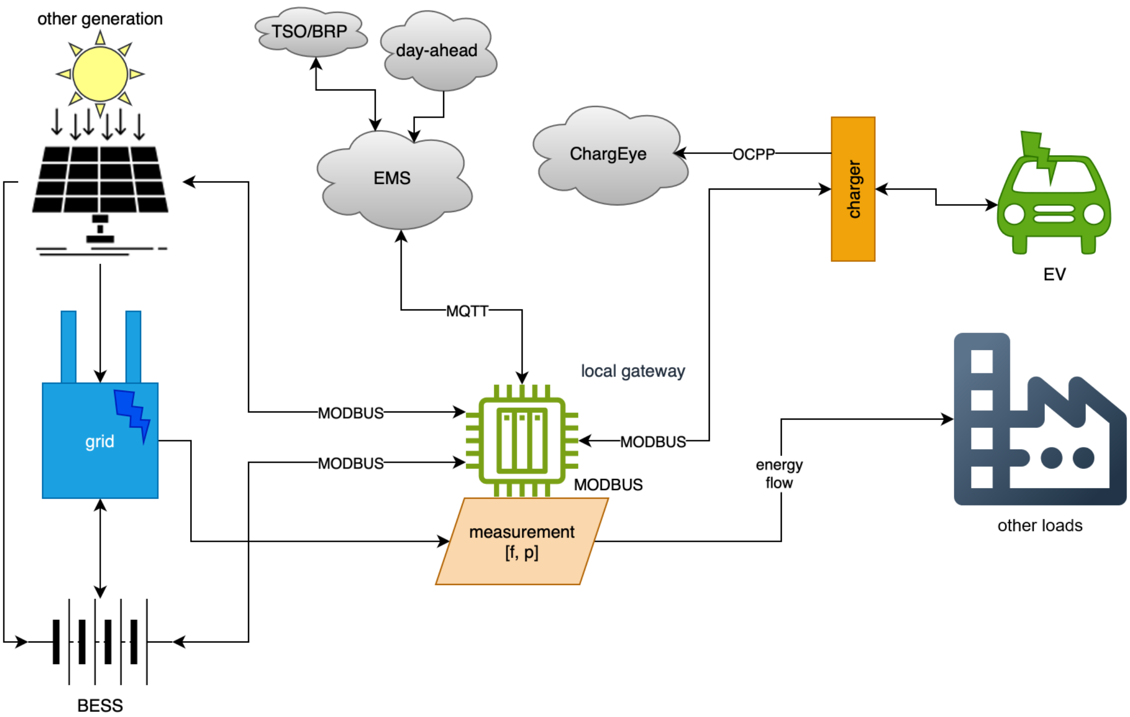

Figure 10 EMS second phase, assets integrated via Modbus TCP.

Third phase of EMS is still being drafted, and final version may differ from the proposal in Figure 11. Here Kempower ChargEye will be acting as the EMS cloud service enabling free customization of the optimization algorithms, use of charging optimization data and aggregation of EMS measurement data along with charging data.

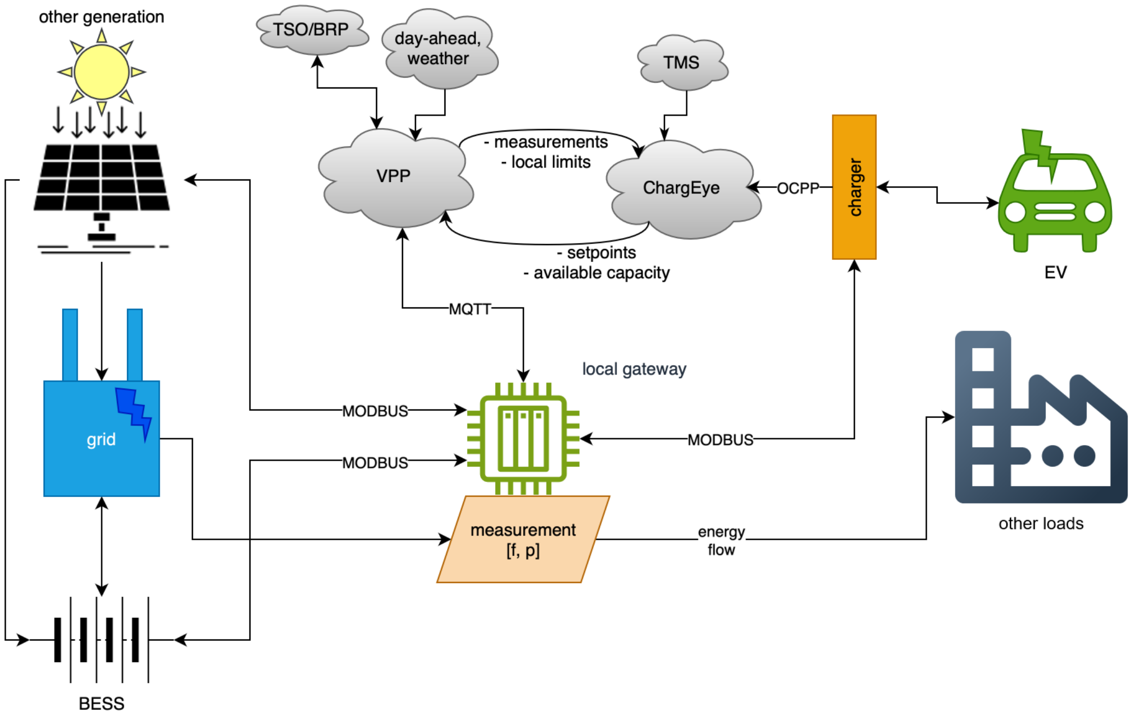

Figure 11 In the third phase of EMS, Kempower ChargEye will be the EMS controller.

5 SET OF KEY PERFORMANCE INDICATORS

5.1 Introduction

This section defines the Key Performance Indices (KPIs) adopted to evaluate the performance, interoperability, and control responsiveness of the AHEAD demonstration activities on both fast and slow charging infrastructures.

The KPIs provide a quantitative framework to assess how each charging technology and management approach performs under the same control objectives, including dynamic load limitation, demand-response activation, and communication reliability.

They are directly linked to the test cases defined for the FAST Chargers Demo and SLOW Chargers Demo , and are used to ensure consistency in comparing the behavior of multi-vendor systems operating under the Spirii backend.

5.2 Methodological Framework

Each KPI is derived from measurements and logs captured during the execution of the defined test cases.

The primary data sources include:

- **OCPP 1.6J messages** (MeterValues, StatusNotification, SetChargingProfile, etc.), recorded through the CSMS.
- **Spirii backend API endpoints**, providing measured current, power, and control commands.
- **Local measurement devices** (MID meters, energy analyzers, and smart breakers) for validation of physical quantities.

All KPIs are computed on a per-session or per-event basis and then aggregated at demo level for cross-comparison between chargers and brands. The same methodology applies to both the FAST and SLOW charger groups, ensuring full comparability across technologies.

5.3 KPI Categories

The KPIs are organized in four complementary categories:

a. Communication & Interoperability

These KPIs quantify the reliability and responsiveness of the communication chain between chargers, backend.

They include:

- **Connection Availability [%]** – ratio of time the charger is online and reachable.
- **OCPP Message Success Rate [%]** – fraction of messages acknowledged without error.
- **Control Command Latency [s]** – delay between command sent by CSMS and charger confirmation.
- **MeterValues Cadence [s]** – observed frequency of measurement reporting.

b. Control & Performance

This group assesses how accurately the chargers follow external control commands and dynamic load limits.

Main indicators are:

- **Following Accuracy [%]** – deviation between commanded and measured current or power.
- **Ramp-Up/Ramp-Down Time [s]** – time to reach the new setpoint after a limit change.
- **Steady-State Error [%]** – residual offset between target and actual steady current.
- **Fallback Behavior** – qualitative indicator describing charger reaction under backend disconnection or limit removal.

c. Energy & Load Management

These KPIs quantify the electrical performance and effectiveness of the load-management strategy.

Typical indicators include:

- **Energy Delivered per Session [kWh]** – metered energy exchanged during a charging session.
- **Peak Power per Site [kW]** – maximum aggregated load across chargers.
- **Load-Limitation Effectiveness [%]** – ratio of observed to target site cap.

- **PV-Matching Index [%]** – proportion of charging energy supplied by local renewable sources during PV-priority tests.

d. User & Operational Aspects

This category covers parameters relevant to user experience and operational stability.

- **Charger Availability [%]** – uptime of the charger for user operation.
- **Session Success Rate [%]** – ratio of completed vs. initiated sessions.
- **Session Interruption Count [–]** – number of aborted sessions due to communication or hardware errors.
- **Authorization Time [s]** – elapsed time between user plug-in and charging start.

Table 8 KPIs for fast charging demonstration.

KPI Name	Description / Objective	Collected / Required Data	Relevance / Expected Insight
Grid Power Reduction Compliance [%]	Quantifies how effectively total site power is reduced following a DSO or aggregator flexibility request during grid-peak events.	Grid import (kW), BESS charge/discharge power, EV charging profiles, and reference setpoints.	Evaluate accuracy of site-level power reduction under flexibility control.
Flexibility Activation Delay [s]	Time delay between receipt of the flexibility command and measurable power reduction at the site.	DSO signal timestamp, OCPP SetChargingProfile timestamp, power measurement timestamps.	Assess control-chain latency and responsiveness of the fast-charging system.
EV Session Continuity [%]	Percentage of active EV sessions maintained without interruption during flexibility activation.	Start/end time, transaction records, power continuity logs.	Quantify user impact of grid-support operations.
BESS Utilization Ratio [%]	Ratio of BESS energy dispatched during flexibility events to available energy capacity.	BESS SOC data, charge/discharge profiles, duration of events.	Determine the role of battery storage in delivering flexibility.
RES Utilization [%]	Share of total charging power supplied by renewable energy (PV or wind) during operation.	PV generation, charging power, site import/export data.	Measure renewable

			integration efficiency.
Command Success Rate [%]	Ratio of successfully executed OCPP control commands (e.g., Set/ClearChargingProfile, RemoteStart/Stop) to total commands sent by backend.	OCPP logs from Spirii backend and fast chargers.	Validate communication reliability and protocol interoperability.
Control Responsiveness (Latency) [s]	Time difference between command issuance and first observed current or power change.	CSMS timestamp logs, charger MeterValues.	Evaluate charger responsiveness to remote control.
Real-Time Power Allocation Accuracy [%]	Comparison between target power limit and actual measured site power during flexibility control.	Spirii API setpoints vs. aggregated site measurement.	Assess control precision and feedback loop quality.
Peak Power per Site [kW]	Maximum total measured site power during operation or testing.	Aggregated power meter data.	Identify load peaks and validate site limit compliance.
Load-Limitation Effectiveness [%]	Ratio between achieved and target load caps during demand-response operation.	Site power readings vs. applied control setpoints.	Quantify the success of centralized control enforcement.
Session Success Rate [%]	Ratio of successfully completed charging sessions to total initiated sessions.	OCPP StartTransaction and StopTransaction logs.	Assess user reliability and session completion rate.
Charger Availability [%]	Uptime of each fast charger within the operational period.	OCPP StatusNotification events (Available/Unavailable).	Quantify infrastructure reliability and communication uptime.
Communication Stability (MeterValues Cadence)	Regularity and stability of MeterValues intervals from fast chargers.	Consecutive MeterValues timestamps.	Evaluate data refresh rate and stability of telemetry link.

Session Interruption Count	Number of sessions interrupted by faults or network loss during operation.	OCPP event/error logs.	Evaluate reliability under real grid-support scenarios.

Table 9 KPIs for slow charging demonstration.

KPI Name	Description / Objective	Collected / Required Data	Relevance / Expected Insight
Command Success Rate [%]	Ratio of successfully executed OCPP control commands to total sent by Spirii backend.	OCPP SetChargingProfile / ClearChargingProfile logs.	Evaluate backend-to-charger reliability and interoperability across brands (Amina, Fronius, Zaptec).
Control Responsiveness (Latency) [s]	Time between sending a control command and first measured power change.	CSMS command timestamp vs. MeterValues update.	Assess charger response speed under load limitation or DR scenarios.
Real-Time Power Allocation Accuracy [%]	Degree to which measured total site power follows the imposed target setpoint.	Aggregated site power vs. Spirii API setpoints.	Quantify accuracy of dynamic load management across brands.
Charger Availability [%]	Proportion of time chargers remain operational and online.	OCPP StatusNotification logs.	Assess reliability of charger connectivity and uptime.
Session Success Rate [%]	Ratio of successful sessions to total initiated sessions under controlled operation.	StartTransaction / StopTransaction logs.	Evaluate user experience stability during active control.
Site-Level Load-Limitation Effectiveness [%]	Ratio of measured total power to applied site limit during load management events.	Site power meter data, control target from Spirii API.	Verify aggregated control success and adherence to site cap.
Communication Stability (MeterValues Cadence)	Regularity of MeterValues reporting interval per charger.	Consecutive MeterValues timestamps from each unit.	Evaluate data reporting stability and network quality.

Grid Power Reduction Compliance [%]	Measures how accurately total site power follows DR reduction requests.	Grid import (kW), OCPP setpoints, MeterValues data.	Evaluate performance of multi-brand system under DR activation.
Flexibility Activation Delay [s]	Delay between backend activation command and observed site power reduction.	Spirii API command timestamp, first observed power drop.	Assess responsiveness of aggregated control in AC chargers.
Load-Limitation Effectiveness [%]	Effectiveness in maintaining site-level power limit during normal operation.	Aggregated power vs. control limit.	Quantify site control stability and compliance.
PV-Matching Index [%]	Ratio of charging energy matched with on-site PV generation in PV-priority tests.	PV production, charger power data.	Quantify renewable energy utilization potential.
Session Interruption Count [–]	Number of sessions that fail or terminate due to communication or control faults.	Event and error logs.	Assess robustness of communication and OCPP implementation.
Peak Power per Site [kW]	Maximum total measured site load during operation.	Aggregated power meter data.	Identify infrastructure stress points and validation of site caps.

5.4 Design of surveys of EV drivers

Surveys will be designed and implemented targeting users of AHEAD' two charging demos in Denmark: a fast charger at a rural main road, and a slow charger in a workplace car park; both chargers are located at/on the Risø DTU Campus. (An additional workplace slow charger is located in Lisbon and may be included in the surveys) If feasible, the two surveys will be complemented by a large-scale survey distributed to EV-drivers in Denmark to enable analysis of aspects that cannot be observed through the demos, but that are nevertheless important for the understanding of charging behavior and preferences, such as charging facilities ('convenience'). The surveys will collect both qualitative and quantitative data.

The goal of this research is to understand EV-driver behaviors and preferences (or 'satisfaction') for the development of an innovative and AI-assisted charging infrastructure that considers the capacity of local electricity grids and an optimal use of variable renewable energy (VRE) resources by enhancing demand-side flexibility.

In terms of the work process, we then first develop a comprehensive questionnaire covering all aspects of behaviors and preferences. This questionnaire will be used for the workplace demo, for which longer interviews are deemed feasible. Reduced versions of this questionnaire will be adapted to the key topics and conditions of the fast charging and large-scale surveys, respectively.

The development of the questionnaire follows a process, starting with 3 research questions, which contain working questions, going on to relevant survey categories, and finally specific questions to be asked. The methodology of developing the surveys is developed in Excel, organized in different columns. The headings of these are presented in Annex 2.

The main research questions are (see working questions in Annex 1):

RQ1. How do EV drivers respond to the price of charging?

RQ2. How does everyday life influence charging behavior?

RQ3. What charging characteristics align best with EV drivers' needs and lifestyle?

The survey categories are:

- Socio-economic status (income, age, gender, residence location, etc.)
- Daily life routine/praxes/needs
- Acceptance of smart charging (public or workplace, not home)
- Driver habits and practices
- Access to private/public charger
- Distance to next charger (general)
- Convenience (technology and facilities)

Annex 1. Working questions for each research question

RQ - Price

WQ 1.1. What pricing scenarios (price variations) are appropriate for fast and slow charging respectively, given the supply of variable renewable energy, grid capacity, and the utilization of the charging stations (i.e., at least 3 considerations may influence the choice of price scheme)?

WQ 1.2. How and when should drivers be informed about the future price of energy?

WQ 1.3. What factors influence the price response of EV drivers?

RQ - Everyday life

WQ 2.1. How do EV drivers plan the charging over a week?

WQ 2.2. What factors influence charging behavior/routines? (Available and cost of home chargers, electricity prices (and taxes), weekend trips, shopping trips, etc.)

RQ - Charging characteristics in relation to needs and preferences

WQ 3.1. How do EV drivers plan EV-charging over a week?

WQ 3.2. What kind of ancillary facilities do drivers prefer?

WQ 3.3. How can drivers best be informed about the availability of a fast charger along a highway, including facilities and prices offered? (via apps, roaming services, signposts, etc.)

Annex 2. Excel work sheet headings

- Type of experiment (fast demo, slow demo, large-scale survey)
- WP7 Objectives
- User Behavior Method of Analysis (qualitative/quantitative)
- AI grid impact Prediction Method (e.g., multifactor regression)
- Charging event data needed from app or charger (collected directly)
- Research questions that will steer the survey design
- Categories influencing behavior
- Variables influencing behavior
- Survey questions
- Questions included the ELBIL questionnaires
- Challenges or considerations for the implementation of the surveys
- Specific methods (e.g., sampling, literature review, data collection in practice, ...)
- Theoretical approach (e.g. microeconomics (price response), everyday life mobility)
- Hypotheses (relating to the research and working questions)
- Feedback from AHEAD partners (ELBIL, DTU. ...)

6 CONCLUSION

Deliverable D7.1 establishes the technical foundation for the Nordic demonstration sites within the AHEAD project, ensuring alignment with the objectives of Task 7.1. By defining detailed specifications, implementation plans, associated test cases, and KPIs, this document enables a structured approach to commissioning and operating the demo infrastructure. The integration of multi-brand AC smart charging at DTU Risø and DC fast charging supported by stationary storage at a highway provides a robust environment for testing interoperability, dynamic load management, renewable integration, and advanced control strategies under constrained grid conditions.

Furthermore, the interoperability between both sites and their connection to the DTU-hosted SYSLAB facilitates centralized monitoring, high-resolution data collection, and coordinated control, thereby supporting comprehensive evaluation of the defined use cases against relevant KPIs. These specifications form a critical milestone for WP7, ensuring readiness for subsequent phases of testing and validation, and ultimately contributing to the AHEAD project's overarching goal of advancing smart and sustainable e-mobility solutions in Europe.

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7 ANNEXES

KPIs specified in WP1.4

7.1 Fast charging KPIs

Key performance indicators			
Link to Use Case	***UC 2***		
ID	***Name***	***Description***	***Comments***
KPI2.1.1	Charging Efficiency	Percentage of power utilization for charging Unit: % efficiency	
KPI2.1.2		Percentage of energy supplied from BESS-RES Unit: % BESS-RES energy used.	Relevant for calculating the CO2 data and environmental benefits.
KPI2.1.3		Percentage of time that the charging station are operational Unit: % uptime	Uptime will affect the ability to utilize RES produced energy and will affect the Grid/environmental benefits. Uptime does also affect the user experience.
KPI2.1.4		Reduction in electricity cost with optimized scheduling Unit: DKK/kWh	Needed to see Dynamic Pricing Impact.
KPI2.1.5		The average amount of energy delivered to EVs per charging session over a given period. Unit: kWh/Session Unit: g CO2/kWh/session	Needed for analysing the Dynamic Pricing Impact and for CO2 data. For CO2 data, also average CO2 values are needed.

KPI2.1.6		The total count of completed charging sessions at the station within a 24-hour or 30-day period. Unit: x/day and x/month Unit: hours charging/day and hours charging/month pr plug	Number per day and month Hours charge plug is occupied pr day/month Needed for the analysis of Dynamic Pricing Impact and CO2 data.
KPI2.1.7 a		The total amount of electricity generated by RES within a specific period. Unit :kWh	Relevant for CO2 data. Has to be deducted from the Grid CO2 values. We need data about what CO2 values the RES energy has in g CO2/kWh.
KPI2.1.7 b		Lifetime emissions for the RES components Unit: g CO2/kWh	We also need data on the g CO2/kWh values for the RES energy.
KPI2.1.7 c		Lifetime emissions for the BESS components Unit: g CO2/kWh	We also need data on the g CO2/kWh values for the BESS energy.
KPI2.1.8		The proportion of the charging station's total energy demand that is covered by on-site RES and BESS, reducing reliance on the grid. Unit: % RES+BESS energy.	Will be needed for calculating CO2 data.
KPI2.1.9		The proportion of RES that is consumed locally for EV charging instead	Needed for evaluating the Dynamic Pricing Impact.

		of being exported to the grid. Unit: % self-consumption	

Key performance indicators

Link to Use Case UC 7

ID	***Name***	***Description***	***Comments***
KPI 7.2.1	Price	The price should be fair and competitive, as long as it does not significantly reduce demand. Unit: DKK/kWh Time of use from KPI2.1.6b	Needed for evaluating Dynamic Pricing Impact. Is related to KPI 2.1.4
KPI 7.2.2	User satisfaction	The user satisfaction can be measured by surveys, and apart from weighting the negative of KPI 7.2.1, as well as KPI 7.2.3, and KPI 7.2.4, a survey may find further user sensitivities. Points to map Was it easy to find?: • Information from navigation system • On mobile app • Signpost Status information: • Occupied • Free Time before charging started Failed to charge Charging speed. Unit kW (maximum and average)	We need contact information on EV drivers to do surveys.

		Price per kWh Environmental choice (how many have chosen to charge environmentally friendly) Charging site/facilities • Did you miss restrooms • Did you miss food facilities • Did you miss shopping facilities Did you charge the amount you had planned to charge? Unit: Yes/No How satisfied where you with the charging session? Value 1-X	
KPI 7.2.3	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 charging (to be minimized) Unit: time queueing (to be minimized)	Needed for analysing Dynamic Pricing Impact. However, waiting time will probably be evaluated differently at a site without facilities compared to sites with more facilities.
KPI 7.2.4	Curtailment avoidance	System constraints can prevent the fast-charging application fulfilling the maximum power request. Therefore curtailment should be minimized. Unit: kWh reduction pr day Unit: time/day (to be minimized)	Needed for evaluating the dynamic pricing impact.

Key performance indicators			
Link to Use Case	***UC 10***		
ID	***Name***	***Description***	***Comments***
KPI10.1	Qualitative Services	Which services can be delivered from the VPP to the distribution grid?	Not relevant for ELBIL responsibilities.
KPI10.2	Quantitative Services	To which extent can services be delivered to the distribution grid?	Not relevant for ELBIL responsibilities.
KPI10.3		Amount of energy imported from the grid in kWh Unit: kWh and start/stop time	Relevant for calculating CO2 values. Must be timestamped to calculate CO2 values and pricing.
KPI10.4		Amount of energy exported to the grid in kWh Unit: kWh and start/stop time	Needed to see how the dynamic pricing has effected the use of RES and the Grid/environmental benefits Must be timestamped to calculate CO2 values and pricing.
KPI10.5		Number of charging sessions, duration, time, power, energy… see D1.1	Is this accumulated sessions?

KPI10.5b		Unit: start time and stop time Unit: kWh pr session BESS-RES: Unit: kWh pr session Prise for energy: Unit: DKK	Data needed to calculate CO2 emissions and utilization rate.
KPI10.6		Amount of CO2 saved, due to charging based on RES, comparison to grid and ICE vehicle. Unit: g/CO2	We also need life sycle CO2 emissions of the RES resources
KPI 10.3		The amount of energy from the RES that can be consumed with the fast chargers. Unit: kWh or %	
KPI 10.4		The share of electricity consumed by the chargers that is provided directly from RES Unit kWh or %	
KPI 10.5		How much the charging cost can be reduced, by having an additional revenue income stream from services to the power grid Unit: DKK/kWh	
KPI 10.6		Time necessary for the communication and control algorithms, time	

		delay for the reaction of chargers Unit: ms	

7.2 Slow charging KPIs

Key performance indicators			
Link to Use Case	***UC 2***		
ID	***Name***	***Description***	***Comments***
KPI2.1.1	Charging Efficiency	Percentage of power utilization when charging Unit: % efficiency	
KPI2.1.2		Percentage of energy supplied from (BESS)-RES Unit: % RES energy used.	Relevant for calculating the CO2 data and environmental benefits.. According to the description of the AC demonstrator, there is no BESS. Only RES measured. We also need data on the g CO2/kWh values for the RES production
KPI2.1.3		Percentage of time that the charging station are operational Unit: % uptime	Uptime will effect the ability to utilize RES produced energy and will effect the Grid/environmental benefits. Uptime will also

			effect the user satisfaction with the charging site.
KPI2.1.4		Reduction in electricity cost with optimized scheduling Unit: DKK or DKK/kWh	Neded to see Dynamic Pricing Impact.
KPI2.1.5		The average amount of energy delivered to EVs per charging session over a given period. Unit: kWh/Session Unit: g CO2/kWh/session	Needed for analysing the Dynamic Pricing Impact and for CO2 data. For CO2 data, also average CO2 values are needed.
KPI2.1.6		The total count of completed charging sessions at the station within a 24-hour or 30-day period. Unit: Sessions/day or Sessions/30 days Unit: hours charging/day and hours charging/month pr plug	Hours charge plug is occupied pr day/month Needed for the analysis of Dynamic Pricing Impact and CO2 data.
KPI2.1.7		The total amount of electricity generated by RES within a specific period. Unit :kWh	Relevant for CO2 data. Has to be deducted from the Grid CO2 values. We need data about what CO2 values the RES energy has in g CO2/kWh.

KPI2.1.8		The proportion of the charging station's total energy demand that is covered by on-site RES (and BESS), reducing reliance on the grid. Unit: % RES(+BESS) energy.	Will be needed for calculating CO2 data. There is no BESS for AC charging at the North Europe demo according to the description earlier in this document.
KPI2.1.9		The proportion of RES that is consumed locally for EV charging instead of being exported to the grid. Unit: % self consumption	Needed for evaluating the Dynamic Pricing Impact.

Key performance indicators			
Link to Use Case	***UC 5***		
ID	***Name***	***Description***	***Comments***
KPI5.1.1	Self-Consumption Rate	The percentage of EV charging energy that comes directly from RES.	Needed for CO2 calculations and grid benefits.
KPI5.1.2	PV Utilization Efficiency	The ratio of PV energy used in for EV charging compared to the total of PV generated.	Needed for CO2 calculations and grid benefits.
KPI5.1.3	Grid Load Reduction	The percentage of reduction in grid's peak power. Unit: % reduction kW	Needed for CO2 calculations and grid benefits.

KPI5.1.4	Number of EV Chargers Supplied by RES	The number of EV chargers that are actively using RES energy as their primary power source.	Needed for CO2 calculations and grid benefits.
KPI5.3.1	Charging Cost Savings	Percentage of cost savings achieved by aligning charging with lower electricity price periods. Unit: % cost savings	Needed for evaluating the Dynamic Pricing Impact.
KPI5.3.2	Grid Load Reduction	The percentage of reduction in grid's peak power. Unit: % reduction peak power.	Needed for evaluating Grid Benefits and the cost reduction for charging.
KPI5.3.3	Controllable Charger Utilization Rate	The efficiency of the twentyfour/seven fully controllable chargers in executing cost-optimized schedules if compared to the standard ones (only turn on or off) Unit: % efficiency (for both these controllable chargers and on/off chargers.	Needed for evaluating Dynamic Pricing Impact. Need data both for these chargers and On/Off chargers to see Pricing Impact over the same time period.
KPI5.3.4	Charging Duration Variability	How much did the cost-optimized scheduling affect the total charging time for each session. Unit time/session (for both cost-optimized and non optimized sessions)	Needed for evaluating the Dynamic Pricing Impact.

Key performance indicators			
Link to Use Case	***UC 10***		
ID	***Name***	***Description***	***Comments***
KPI10.1	Qualitative Services	Which services can be delivered from the VPP to the distribution grid?	Relevant for evaluating the grid benefits.
KPI10.2	Quantitative Services	To which extent can services be delivered to the distribution grid?	Relevant for evaluating the grid benefits.
KPI10.3		Amount of energy imported from the grid in kWh Unit: kWh and start/stop time	Relevant for calculating CO2 values. Must be timestamped to calculate CO2 values and pricing.
KPI10.4		Amount of energy exported to the grid in kWh Unit: kWh and start/stop time	Needed to see how the dynamic pricing has effected the use of RES and the Grid/environmental benefits Must be timestamped to calculate CO2 values and pricing.
KPI10.5		Number of charging sessions, duration, time, power, energy… see D1.1	Is this accumulated sessions?
KPI10.5b		Unit: start time and stop time Unit: kWh pr session	Data needed to calculate CO2 emissions and utilization rate.

		RES: Unit: kWh pr session Prise for energy: Unit: DKK	
KPI10.6		Amount of CO2 saved, due to charging based on RES, comparison to grid and ICE vehicle. Unit: g/CO2	Needed for evaluating environmental benefits.
KPI 10.3		The amount of energy from the RES that can be consumed with the slow/fast chargers. Unit: kWh or %	
KPI 10.4		The share of electricity consumed by the chargers that is provided directly from RES	
KPI 10.5		How much the charging cost can be reduced, by having an additional revenue income stream from services to the power grid Unit: DKK/kWh	
KPI 10.6		Time necessary for the communication and control algorithms, time delay for the reaction of chargers Unit: ms	