Deliverable D5.3: Real-World Demonstration Actions

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Abbreviations and Definitions

AC	Alternating current
API	Application Programming Interface
BESS	Battery Energy Storage System
BMS	Battery Management System
CAN	Controller Area Network
CCS	Combined Charging System
CP	Control Pilot
DC	Direct current
DER	Distributed Energy Resources
DSO	Distributed System Operator
EMS	Energy Management System
EV	Electric Vehicle
EVSE	Electric Vehicle Supply Equipment
HDV	Heavy Duty Vehicles
HLC	High Level Communication
HPC	High Power Charging
HVDC	High Voltage Direct Current
IEC	International Electrotechnical Commission
ISO	International Organization for Standardization
KPI	Key Performance Indicator
LFP	Lithium Iron Phosphate
MMC	Microgrid Main Controller
MPPT	Maximum Power Point Tracking
MQTT	Message Queuing Telemetry Transport
OBC	On Board Charger
OEM	Original Equipment Manufacturer, here automotive manufacturers

OCPP	Open Charge Point Protocol
PCS	Smart Power Control System
PMS	Power Management System
PLC	Power Line Communication
PV	Photovoltaic
PWM	Pulse Width Modulation
REC	Renewable Energy Community
RES	Renewable Energy Sources
SoA	State of the Art
SOC	State of Charge
TSO	Transmission System Operator
VPP	Virtual Power Plant
V1G	Unidirectional charging
V2G	Vehicle-to-Grid
V2H	Vehicle-to-Home
V2B	Vehicle-to-Building
V2X	Vehicle-to-everything

1. Executive Summary

The overarching goal of the XL-Connect project is the optimization of the complete charging chain – from energy supply to the end consumer. One main optimization aspect being the charging process and the utilization of smart charging and bidirectional charging functionalities. To maximize the potential of these functionalities, the development of adequate charging strategies is necessary and shall be realized within the XL-Connect project.

These strategies shall be tested in several virtual and real-world demonstrations, within the work-package 5 of the XL-Connect project. The real-word demonstration provides the proof of feasibility of these strategies in a real context. Beside private demonstrations, that are more controllable regarding the access of users, public demonstrators will also be implemented to acquire realistic user-data and verify the technical feasibility of the Electric Vehicle Supply Equipment (EVSE) and the algorithm with a wide range of EVs. In addition, virtual demonstrations will cover use-cases with a higher amount of EVs as well as more complex use-cases.

As planned during Task 5.1, each real-world demonstration action is addressing a different case study with different methods, which depend on the context of the application and on the initial scopes to be addressed. All the activities contribute to the common scope of grid energy exchange management. Due to the limitations determined by cost constraints and due to the technology available, two main difficulties have to be addressed:

1. Demonstration sites involve a limited number of devices, and the power of the specific hardware is sometimes limited to typical 11 kW charging methods
    a. A solution is provided by the creation of a “digital twin”, a model which scales-up the solution on a broader number of elements or with an increased power
2. V2G systems based on the latest CCS standard are still rare on the market, both in terms of converters for the infrastructure EVSE and in terms of vehicles on the market. Consequently, the number of V2G-enabled vehicles circulating in the uncontrolled environment is also negligible
    a. For real world demonstrations, suitable solutions have been planned and implemented using emulators and/or storage batteries which can perform bidirectional power exchange

This deliverable provides an overview of the real-word demonstrations treated in this project. Therefore, the geographical and grid circumstances of each real-world demonstrator are shortly addressed. Then, a description of scopes, methods, expected results is provided together with an explanation of the status according to the most recent information available per each of the five demonstration actions. In addition, a plan for demonstrator implementation and for its operation during the second part of XL-Connect project is provided. Finally, this deliverable provides an overview of the links between the virtual and real demonstrations and lists the possible risks of the real-world demonstrations.

Keywords: smart charging, V2G, V2B, energy communities, simulated use-cases, real-world use cases, demonstrations, demonstrator, OCPP 2.x, ISO 15118-20.

2. Introduction to Real-World Demonstration Actions

The demonstration actions of XL-Connect described here have the ambition to implement in real systems a few typical scenarios, to demonstrate in the partner context - here, and now - the applicability of the most recent technologies for charging power management, with particular reference to CCS technology and to the latest release of the ISO 15118-20:2022. The demonstration action will involve both real case studies—considering a specific group of EVSEs, vehicles, and users—and digital twin simulations of the real case, where the application of individually viable concepts is modelled and up-scaled to provide a forecast on future sustainability.

Task 5.3 focuses on executing Real World Demonstrations to validate the advanced charging concepts developed in Task 4.1; methods developed in Task 5.2 for virtual environment creation are also adopted. The objective is to assess and showcase their performance, particularly aiming to achieve a possible 50% reduction in energy exchange with the grid. This task involves practical implementation across five demonstration actions in four European countries (cf. Figure 1), each addressing distinct aspects of the advanced charging systems.

Figure 1. Map of the XL-Connect demonstration actions.

The demonstrations are designed to cover a diverse range of applications and are fully detailed in Deliverable 5.1. Here is a brief summary:

- **Generic Communication Structure/Open Standards**: Conducted in Germany (Aachen) with FEV, Regionetz, and RWTH University, emphasizing interoperability and standardized communication protocols.
- **Public Area/University Campus:** Located in Italy (Florence), leaded by the University of Florence, demonstrating solutions for university campuses and public areas.
- **Microgrid for Large Parking Areas**: Conducted in Italy (San Giovanni Valdarno) with ABB, targeting large parking facilities, including those for heavy-duty vehicles.
- **Sector Coupling:** A pilot in Belgium (Brussels), made by ABEE, focusing on the integration of energy sectors. Hydrogen sources for energy storage and conversion are adopted in this pilot case study, together with a DC-based energy distribution system.
- **Interoperability**: Demonstrations in three cities in Portugal, led by E-REDES, to validate seamless interaction between different systems.

The task builds on inputs from Deliverable 4.1 (Advanced Charging Concept), Deliverable 5.1 (Orchestration of Demonstration Actions) and partly to Deliverable 5.2 (Virtual Demonstration actions). The findings and data collected from these demonstrations will contribute to subsequent analyses, including Task 5.4, where real-world data will be acquired, organized, treated and assessed to evaluate system performance.

The following sections provide a detailed overview of each demonstration action, covering system setup, data acquisition configurations, and strategies for risk management. Where available, preliminary results on the reduction of energy exchange with the grid are also presented and analysed. Finally, a summary of data management and risk mitigation strategies is included. This deliverable marks a significant milestone in validating the technical and operational feasibility of the proposed advanced charging concepts.

2.1 Status of Demonstration Actions

This deliverable is scheduled for completion at month 24. However, due to delays already identified as potential risks in Deliverable 5.1, only the Aachen demonstrator is currently operational. The other demonstrators are in the final stages of setup, with completion expected by the first months of 2025. Given the shorter period of active operation for these demonstrators, a comprehensive risk and mitigation plan has been developed for each site. This plan includes detailed tables outlining specific risks, potential impacts, and corresponding mitigation actions to ensure that any interruptions are quickly addressed and that operational goals are achieved as effectively as possible. Despite these delays, the use of digital twin simulations for the demonstrators has proven invaluable. These simulations have allowed the partners to test and analyse various scalability scenarios, enabling a robust assessment of system behaviour under different conditions and operational challenges. This approach not only compensates for the reduced physical demonstration period but also enhances our understanding of potential outcomes and performance metrics, ensuring a strong foundation for the project's success and future deployment (cf. Figure 2).

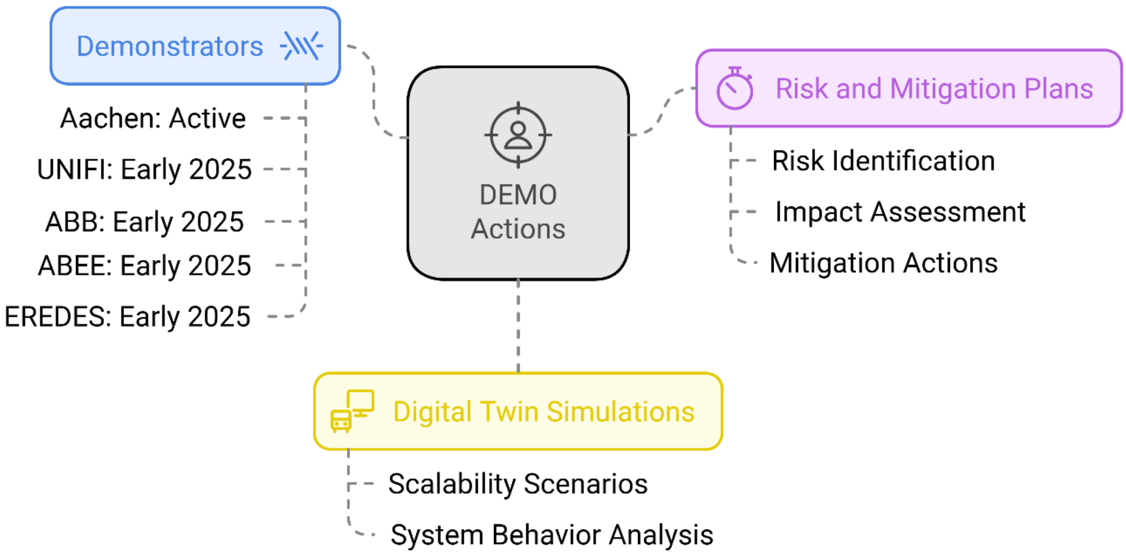


Figure 2. Demonstrators' overall status.

2.2 Relation to Virtual Demonstration

The real-world demonstration activities build upon and complement the insights gained from the virtual demonstration use cases described in detail in the Deliverable 5.1 and performed in Task 5.2. By integrating findings from the simulations, the real-world demonstrations provide a validation of the digital twin's accuracy and scalability in representing complex charging point systems. This interaction allows for a deeper understanding of how theoretical models translate into practical applications, especially in the context of emerging energy and mobility technologies and of how small practical application can be scaled up into high adopted applications.

For instance, while the virtual use cases highlight the potential benefits of renewable energy communities (RECs), vehicle-to-building (V2B) solutions, and vehicle-to-grid (V2G) applications, the real-world demonstrations enable the exploration of these concepts under real conditions. Specific aspects such as grid stability, environmental impact, user acceptance, and economic feasibility are assessed, offering invaluable data to further improve the digital twin. The virtual demonstrations are briefly summarized below:

- **Energy Communities with Charging Park Areas**: A simulation model in MATLAB-Simulink was used to investigate the potential of Vehicle-to-Grid (V2G) and Vehicle-to-Grid (V1G) setups to reduce energy costs and grid exchange in energy communities.

- **Vehicle-to-Building (V2B) Solutions for Industrial Sites**: The virtual use case comparing V2B setups to local storage solutions highlighted the potential of V2B as an alternative to conventional storage.

- **Bidirectional Charging in Smart Cities:** Virtual simulations explored bidirectional charging applications in urban contexts, influenced by user behaviour models incorporating factors such as range anxiety, willingness to wait, and battery health. These simulations are showing that charging activities increase significantly with higher EV penetration rates.

The real-world demonstration activities are essential extensions of the virtual use cases, enabling practical validation and providing critical insights to refine and scale the digital twin. These demonstrations address the limitations of simulations and explore the feasibility of innovative energy solutions under diverse conditions.

For example, the virtual use case on bidirectional charging in smart cities, which explored ISO 15118 communication protocols and user behaviour models, can be directly linked to the real-world demonstration conducted in Aachen, Germany. This demonstrator, led by FEV, Regionetz, and RWTH University, focuses on validating interoperability and communication standards in practice, paving the way for scaling such solutions to larger urban EV ecosystems.

Similarly, the renewable energy community (REC) virtual use case, which highlighted the potential for reducing energy costs and increasing self-sufficiency through optimized energy management, is being tested in real-world conditions at the University of Florence, Italy. This demonstration explores the application of REC setups in a university campus and public areas, providing a framework for scaling these solutions to other community settings. Results of this correlation are shown in section 4.1.

In San Giovanni Valdarno, Italy, ABB's real-world demonstrator targeting large parking areas builds on the virtual use case findings related to energy management in parking facilities. By incorporating microgrids, and bidirectional charging, this demonstrator validates the feasibility of these solutions in practice and offers a basis for scaling up to parking areas for heavy-duty vehicles and larger fleets.

The sector coupling virtual use case, which investigated the potential of vehicle-to-building (V2B) setups and waste heat utilization in industrial contexts, finds its practical counterpart in the demonstration conducted in Brussels, Belgium, by ABEE. This real-world site validates the feasibility of sector integration and explores the scalability of V2B systems for larger industrial applications.

Finally, the virtual use case on bidirectional charging in smart cities, which modelled the behaviour of aggregators under different EV penetration rates, is linked to real-world demonstrations in Portugal. Led by E-REDES, these pilots validate the performance of aggregators in managing charging activities and provide insights for scaling solutions to urban environments with varying levels of EV adoption.

Together, the real-world demonstrations and virtual use cases form a comprehensive framework that links simulations findings with practical implementation, ensuring that the digital twin reflects the complexities and challenges of real-world energy systems.

3. Aachen Demonstration

The Aachen demonstration project involves three partners: FEV, Regionetz, and RWTH University that are focusing on the generic communication structures and open standards for bidirectional charging. This includes the communication between the EV and the EVSE, as well as the EVSE and the back end. A crucial component for testing these communications is the bidirectional EVSE.

As stated in the deliverable D5.1, three 11kW CCS2 charging stations shall be used in the Aachen demonstration. We placed an order for these EVSE beginning of December 2023 with an expected delivery date in the second to third quarter of 2024. However, our supplier, “Ambibox”, is currently facing challenges that have delayed these delivery dates, and we now expect the EVSE to arrive only in the second quarter of 2025.

The three ordered VW ID.4 vehicles arrived in Aachen in early 2024 and were equipped with the wrapping, as can be seen in Figure 3.

Figure 3. Picture of the three VW ID.4 vehicles used in the Aachen demonstration.

Due to the significant delay in receiving the EVSE, the focus of the Aachen demonstration in the last year shifted from the EVSE centric system described in deliverable D5.1 to a more user centric system. This change allows us to start collecting valuable user data relevant to our Aachen use case, which will be useful for simulations and help develop a user prediction model. The main goal remains the testing of bidirectional charging based on open communication structures as soon as the correlating EVSE arrives.

The following sections describe the current system setup, provide an insight into the collected data until this point and outline an outlook after the arrival of the EVSE as well as the related risks.

3.1 System Setup

The vehicles were acquired for the XL-Connect project and are freely useable by all participants of the Aachen demonstration. However, since bidirectional charging is not yet possible due to the lack of necessary hardware, the only feasible way to discharge the vehicle batteries is through driving. Unfortunately, the participants of the Aachen demonstration don’t have a necessity for regular business trips. Therefore, vehicle user access got extended to Regionetz technicians that regularly use the ID.4s as company pool vehicles.

The Regionetz company is responsible for the electricity, gas, district heating, water and sewage grids in the city and urban region of Aachen. Regular construction work is required at various locations in Aachen to maintain and expand these networks. Consequently, it is often necessary for Regionetz technicians to travel to these construction sites. The ID.4 vehicles have been available for this purpose since February and are parked in the Regionetz parking lot in between the use of technicians.

Each vehicle is assigned a dedicated standard 11kW AC charging point that is reserved exclusively for that vehicle. When not in use, the vehicles should be connected to their respective charging points. With the exception of business trips taken by Regionetz technicians or demonstration participants, these vehicles are primarily used during typical working hours.

To streamline vehicle usage and coordination among all users, we have implemented a booking tool, described in section 3.2.

3.2 Booking Tool

The booking calendar is based on an outlook email address (“xl-connect@mmp.rwth-aachen.de”), whose calendar is openly accessible for all users. When a user wants to book the vehicle, he sends a meeting request with the following information, as also displayed in Figure 4:

- *Title*: Number-plate of the desired vehicle (e.g. AC-RN138E, or 138)
- *Location:* Planned distance in km to be travelled during the usage
- *Start and end time* shall be corresponding with the time of vehicle usage

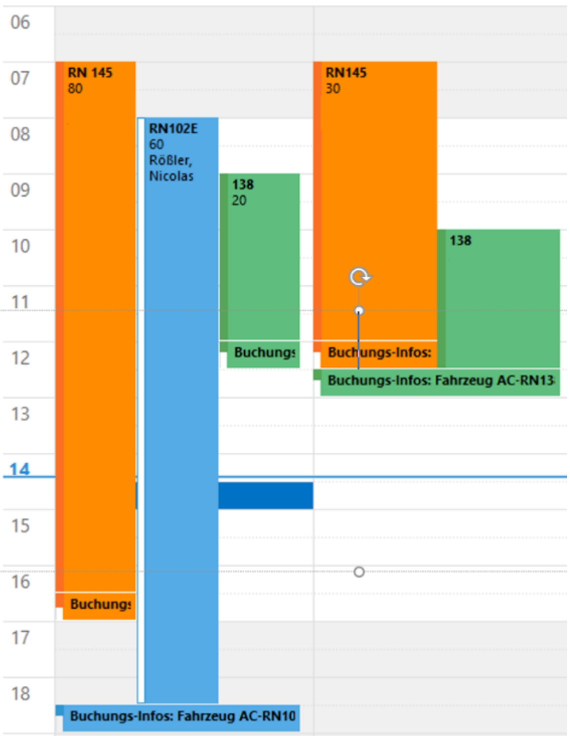


Figure 4. Extract from the booking outlook calendar.

Within this project, a booking tool was developed to accept/decline these meeting request, later named bookings, based on several conditions (e.g. correctness and completion of the meeting-request, permission of the user, interference with a present booking, booking duration within set boundaries). The booking tool is a python script accessing the outlook exchange account over an API provided by Microsoft outlook.

The functionality of the booking tool is similar to room-bookings within a company with some additional features.

However, the utility of this tool goes beyond the coordination between the users. As mentioned in the deliverable D5.1, when charging bidirectionally the “DepartureTime” and the “EVEnergyRequest” need to be provided by the EV to the EVSE, according to the ISO 15118-20. These values are directly accessible from the booking calendar: the departure time matches the start time of the next booking, and the desired energy can be calculated from the planned distance and an estimated energy consumption (e.g. 20 kWh/100 km).

Assuming the booking by the users are made far in advance and always reflect the real vehicle usage, it can be ensured that the vehicle SoC fits the users need and user impairment through bidirectional charging will later be avoided. However, in reality the booking by the user does not perfectly match the real vehicle usage. Also, some users might book the vehicle right before the drive or not book the vehicle in case of unplanned incidents. This user behaviour is being analysed during the project and an exemplary extract for one vehicle is displayed in Figure 5.

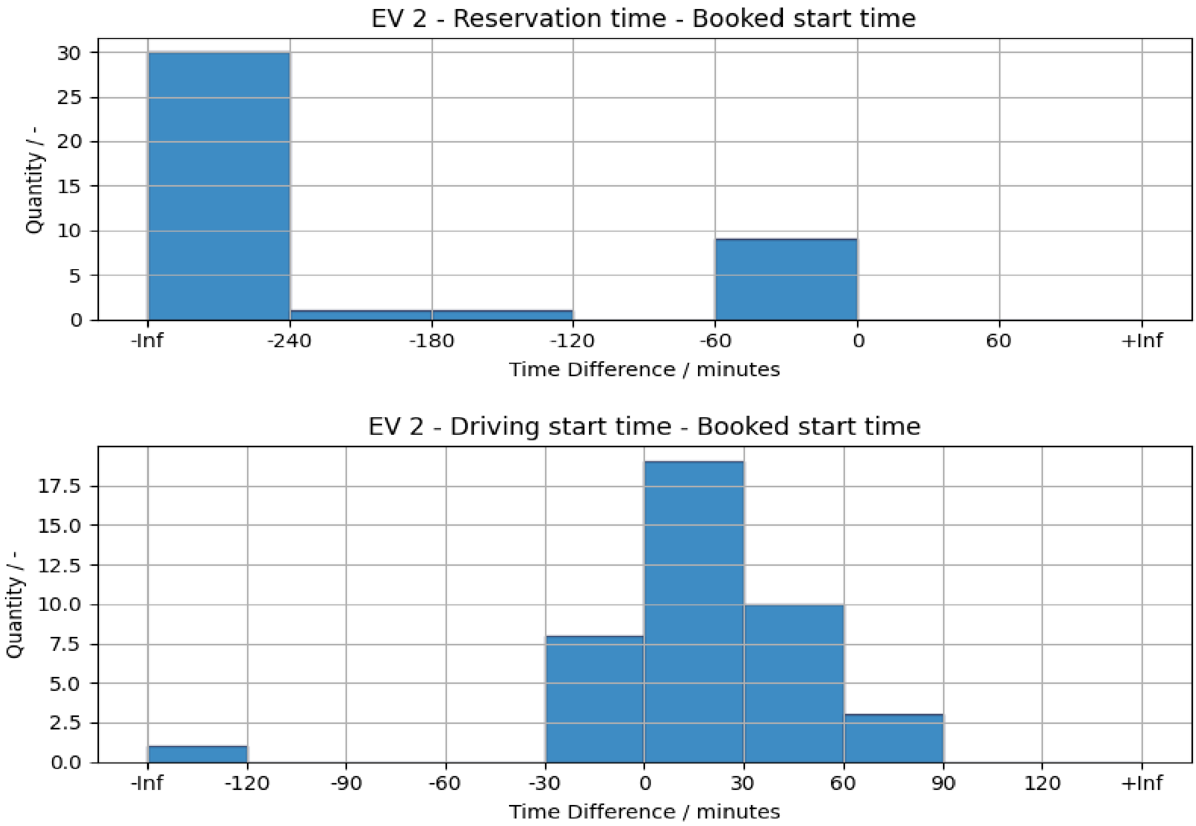


Figure 5. Earliness of bookings (top) and comparison between the driving start time and the booked start time (bottom) exemplary for EV 2.

From the top plot, it can be seen that for EV 2, 73% of bookings are made at least four hours before the booking starts. In the bottom plot, the difference between the booking time and the actual start time of a drive is displayed. Positive numbers mean that the drive started later than the booking, negative numbers mean that the drive started earlier than the booking. Here it can be seen that 90 % of drives start within 60 minutes of the booked time and that the drive mostly starts after the booked time. Therefore, reservations are made in advance, and the users can estimate their departure time accurately.

From these observations it can be concluded that the booking tool is a good basis for the usage prediction of vehicle 2, since the charging event is plannable and the SoC of the vehicle will be sufficient when the drive starts. These results are just exemplary for EV 2 and will be made for every of the three vehicles with the data we are collecting. Also, it needs to be mentioned that some drives were not booked by the users as they were too spontaneous. These drives are not included in Figure 5.

In order to create the shown comparisons between the booked start time and the actual start time of the driving event, vehicle data is required in addition to the described booking information. The retrieval of the vehicle data is described in the next section.

3.3 Vehicle Data Collection – VW API

With the introduction of the ID-series, VW also released a new service named WeConnect, which allows for an API connection to its vehicles. The accessible vehicle data includes the current mileage of the vehicle, the current SoC, the current charging power, the information if a charging plug is inserted, the parked location, as well as the battery temperature. Every four minutes, this data is automatically collected and saved for the three ID.4. The data collection started and has been running since May 2024.

Several participants of the Aachen demonstration also used one of the three vehicles to drive to the XL-Connect general assembly in Barcelona in May 2024. In addition to the available data from the WeConnect API, an additional GPS device was used to track our position and velocity during the trip, as displayed in Figure 6:

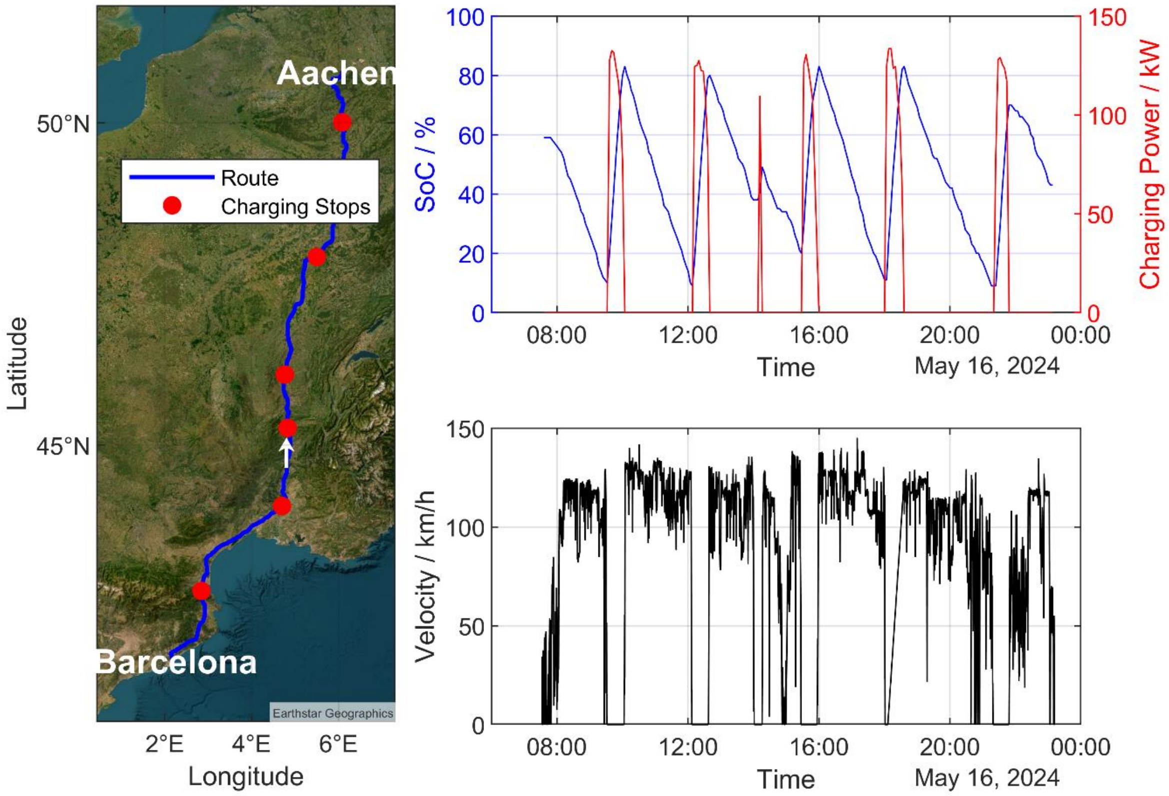


Figure 6. Trip back from the XL general assembly from Barcelona to Aachen with tracked vehicle SoC, charging power, velocity and position.

Longer trips as the one to Barcelona are an exception. Usually, the vehicles are only used around Aachen and charged at Regionetz. As described later, the data is available to the other partners over the database and can be used for simulation of this company pool car use case & for user prediction models in WP4.3.

In addition to retrieving data, the WeConnect API also allows for requests to be sent to vehicles. Possible options are starting the climatization of the cabin, activating the start light or activating the horn. The more relevant possibility for this project is the option to stop and later restart an ongoing charging process. This option allowed us to implement a smart charging strategy for vehicles without access to the EVSE and is described in the following.

3.3.1 Energy Management System

The energy management system for the Aachen demonstration is running on a single-board computer, a raspberry pi 4B. Beside the energy management system, the described booking tool and the VW data collection are also running as separate processes on the raspberry pi. A schematic of all the functionalities and the exchanged data between them is displayed in the Figure 7:

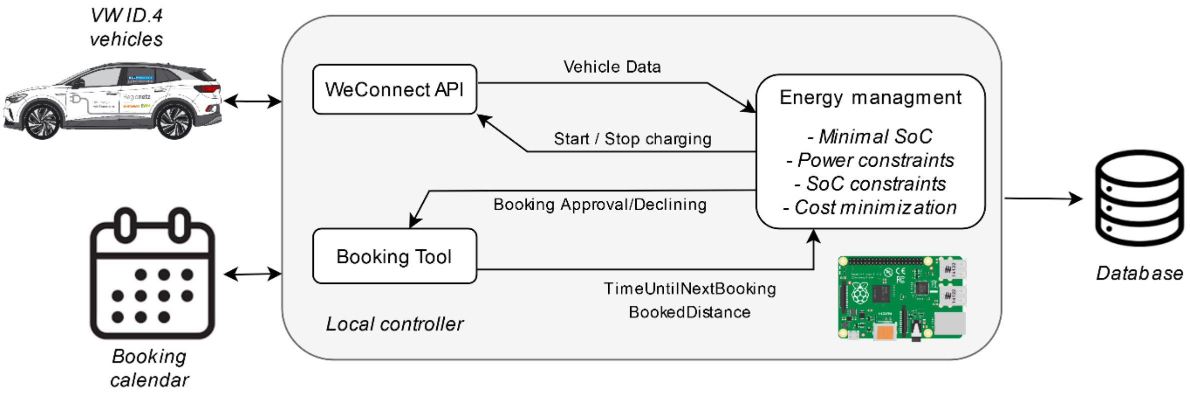


Figure 7. Current system overview of the Aachen demonstration.

The data provided by the booking tool are the “TimeUntilNextBooking”, as well as the “BookedDistance”. Up to three bookings in the upcoming 24 hours are considered by the optimizer. The data provided by the WeConnect API is the SoC of the vehicles, the current charging power, the charge plug status and the location of the vehicle. Additionally, the day-ahead electricity price is fetched from an online available API. This information is forwarded to the optimizer that computes a setpoint SoC for the connected vehicles which is transformed into a “charging” or “stop charging” command in order to be sent to vehicles with WeConnect again. This setup allows to test different smart charging strategies with different goals.

Although all the functions running on the raspberry pi are coded within python scripts, we opted for a MATLAB Simulink optimizer instead of a python based one. The optimizer is compiled with a support package for raspberry pi provided by MathWorks and can be called using python. This setup allows to run simulations with the same optimizer on a separate PC but with adapted inputs and directly compare the results to the ongoing real-world demonstration.

The nonlinear optimization based on the MATLAB “fmincon” function from the optimization toolbox allows the consideration of linear and non-linear equality and inequality constraints, as well as lower and upper bounds for its outputs. The optimization goal currently implemented is the minimization of the electricity price within the predicted horizon of 24 hours, while fulfilling the desired SoC of all three vehicles before the next booking starts. Another constraint is the minimal SoC up to which the vehicles shall directly be charged after connecting them to the EVSE. This value is parametrizable and is currently set at 45 %. One exemplary charging process collected from the real world is shown in the following Figure 8:

Figure 8. Extract of the data stored on the database of vehicle 1.

It is shown that although the vehicle is plugged-in for long periods of times, it is only charged at specific times. At first plug-in, the EV is charging up to 45 % SoC and keeping the SoC constant for hours, before charging it to 52 % before the next booking (shown by the red availability bar). Afterwards the vehicle is being used for some time (shown by the increasing mileage and the unplugged status). At plug-in of the vehicle, it is again only charged up to 42 %, awaiting the next booking. It can also be seen that data at the beginning and the end of the plot is missing; This is addressed later in the Chapter 3.3.2.

The Figure 8 is directly taken from the database that was setup within this project by the colleagues from FEV as part of their WP5.4 efforts. Within chapter 3.3.2, the integration of data from the Aachen demonstration into the database shall be briefly described. A full report will be delivered as part of deliverable D5.4.

3.3.2 Database – Collaboration with WP5.4

As mentioned before, all data generated by the Aachen demonstration is currently being collected on one single device, a raspberry pi. It is saved on the device locally and can be accessed by other scripts (e.g. the energy management), when needed. Another process on the raspberry pi is to send out all the locally stored data to the database, as already shown in Figure 7. This is done with a network protocol named MQTT (Message Queuing Telemetry Transport), which is a usable for machine-to-machine communication and is based on a publish-subscribe principle. MQTT is ISO recommended, often used in home automation and integrated into python with online available packages.

For our demonstration purposes, FEV set up the database and provided us an authentication method so that we can publish our data to the database. The definition of topics for each value was done in a way to be applicable to all other demonstrations as well. The database is currently running on a FEV server and can be accessed by all members of the XL-connect consortium. Besides the data storing capabilities of the database, the available datapoints are also visualized. All vehicle data mentioned in chapter 3.3 from the Aachen demonstration for the second half of 2024 is available.

The Aachen demonstration was a small-scale example of how this database should be set up. In November of 2024, the manual on how to publish data to database was also provided to all project partners by FEV. Also, the possibility of manual or automated data extraction from other demonstrations is possible, which is of high interested in simulations.

3.4 Outlook and Risks

Since the arrival of the bidirectional EVSE hardware from “Ambibox” for the Aachen demonstration got delayed, we shifted our attention to available hardware, the ID.4 vehicles. Within the last year, the Aachen Demonstration setup a booking tool in order to comprehend the user behaviour for our use case, we are retrieving vehicle data from the VW ID.4s, we helped setup a database for all demonstrations, we are publishing our data on this database for all partners and have implemented a smart charging strategy for the VW ID.4s based on ON/OFF charging.

The smart charging algorithm is in place since September 2024 and has been continuously improved since then. Undesired behaviours like lost WiFi connection, unavailable WeConnect API or price API and maintenance of outlook need to be considered when dealing with real demonstrations. These issues where not always foreseen and have led to missing data on the database or uncontrolled charging events, as can also be seen in Figure *8*.

Nonetheless, the Aachen demonstration is already set up for bidirectional charging and will be ready to implement it as soon as the first compatible hardware arrives. The current optimizer is prepared for bidirectional charging; we simply need to adjust the charging constraints, particularly the power limits of the running optimizer. Additionally, communication with the vehicles must be extended by the communication to the EVSE, following the OCPP 2.0.1 protocol. Implementing this protocol will be the next step for the demonstration while we await the arrival of the bidirectional EVSE units.

One major risk for the demonstration is the unavailability of the ISO15118-20 protocol on the vehicle side. Until this date, the VW ID.4 does not have the option to communicate with the -20 protocol. This was tested on several occasions throughout the last months with measurements checking the Power-Line-Communication (PLC) between the vehicle and a DC charger. Proprietary solutions to charge bidirectionally based on the ISO15118-2 are an alternative, if they are released by VW. This risk will be also addressed in the chapter 8.2, as it affects all demonstrations.

4 University of Florence Demonstration

In the University of Florence (UNIFI), a demonstrator in a public area is being implemented. As detailed extensively in Deliverable 5.1, the UNIFI demonstrator is a pioneering energy management initiative in Italy and Europe, aimed at creating an energy community in public spaces to power EV charging stations. It promotes energy awareness, supports the transition to electric mobility on a non-profit basis, enhances local charging infrastructure, and collects data to optimize and expand energy management across University of Florence facilities in Tuscany.

The demonstrator consists of two main sites located in the Municipality of Calenzano. A control system will manage the energy exchange between these sites, optimizing the impact on the electricity grid based on the availability of other elements such as photovoltaic systems. The identified geographical areas are suitable for establishing Energy Communities in compliance with ARERA resolution 727/2022/R/eel. These two sites (cf. Figure *9*) can be described qualitatively as follows:

1. **MOVING LAB** located at Via Vittorio Emanuele 32 within the Department of Industrial Engineering laboratory, is accessible exclusively to University of Florence members. It features 2 DC and 1 AC charging points, a mobile shelter with a photovoltaic system, a control system for monitoring and remote management, and a battery storage system. The project also involves the adjacent building housing the Department of Industrial Engineering laboratories, which is characterized by high energy consumption, making it an ideal setting for testing and optimizing energy management solutions.

2. **CAMPUS DESIGN** situated on public land near the UNIFI building in Calenzano, includes the energy management of 3 existing charging points already installed by a local provider and offers free public access for the citizenship and the students.

All the systems installed in areas open to the public will correspond to commercial and/or pre-series products that fully comply with the safety regulations and product directives required for the sector. Also, the **MOVING LAB** systems have been submitted for review and approval by the relevant university department to ensure compliance with institutional standards and operational requirements.

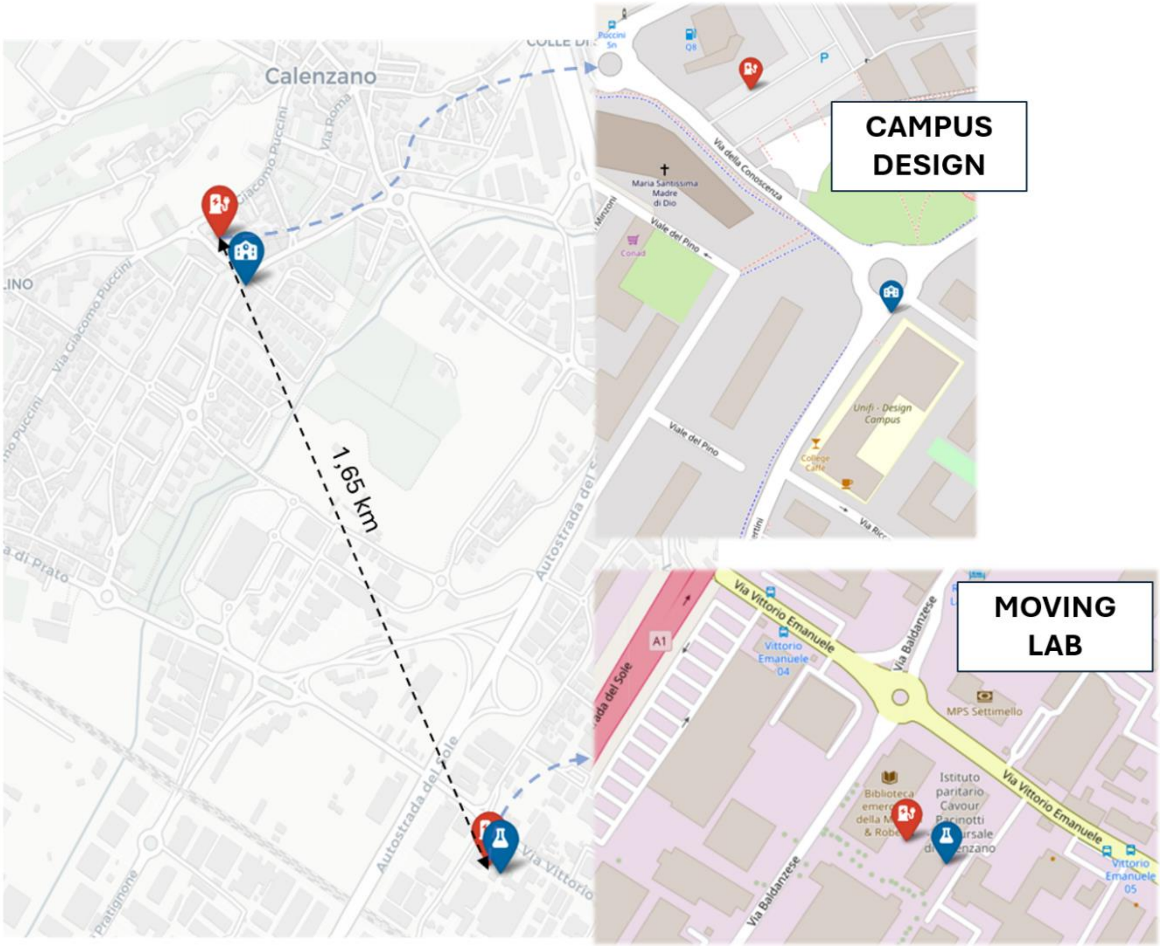


Figure 9. UNIFI Demonstration Features. For the CAMPUS DESIGN, the map shows a possible location point in which operative charging points are already installed.

As a control logic, the approach described in Deliverable 5.2 will be implemented, with parameter settings aligned with the system setup. Since the system's scale has been aligned with the XL-Connect scope, preliminary results were obtained by matching photovoltaic system's capacity to the energy demand required for the **MOVING LAB** and the **DESIGN CAMPUS** ‘charging stations. These results, presented in the following section, highlight the potential benefits of applying the control logic on a larger scale, while also providing a critical foundation for testing and validating its implementation. The scaled design highlights fostering a culture of energy optimization and demonstrating innovative EV charging technologies, with objectives such as reducing grid impact, maximizing energy value, and improving user satisfaction. Additionally, data collected will guide the planning of larger-scale investments. For example, the photovoltaic shelter in the **MOVING LAB** is expected to meet approximately 2% of the site’s annual energy needs, while the area itself could theoretically accommodate a more extensive photovoltaic installation capable of covering 75–100% of energy demand. If such large PV system will be installed in the future, it is expected that in order to meet the yearly request of the site a relevant overproduction would be expected in certain daily hours, determining a strong imbalance between production and request.

Currently, the **MOVING LAB** demonstrator is in the final phase of component procurement, with installation anticipated at the beginning of 2025 due to bureaucratic needs related to installation on university grounds. While these delays may pose a risk to achieving the project's objectives within the planned timeframe, mitigation measures include close collaboration with university authorities to expedite necessary approvals and parallel progress on preparatory activities such as software development and testing. A risks section is also present below. For the **CAMPUS DESIGN** unit, two main providers have been identified to secure access to an already installed and operational charging point. Access has been obtained on December 2024, and comprehends 6 charging units (12 connectors in total) managed by the XL-Connect partner ESTRA. Consequently, the implementation of the control logic is planned for the end of the first quarter of 2025. Lastly, the data acquired will serve as a basis for evaluating the system's performance and informing potential future optimizations and developments. The Gantt of the UNIFI demonstrator is shown in Figure 10.

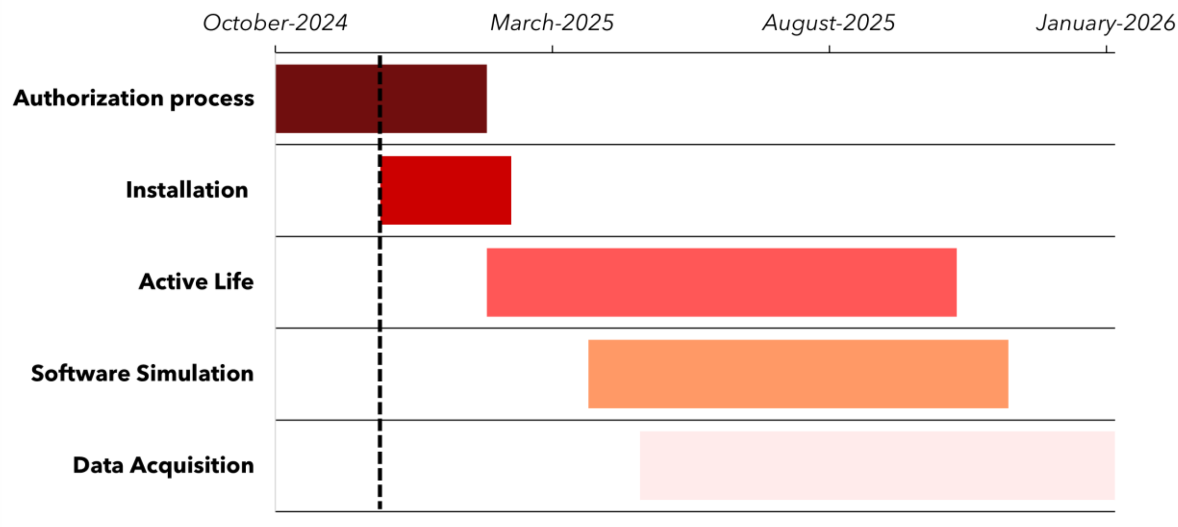


Figure 10. UNIFI Demonstrator Gantt.

In the next section, the control logic and its results will be thoroughly evaluated. Following that, the system setup and risk management will be presented.

4.1 Evaluation of Control Logic and Potential System Benefits on a Large Scale

The scalable model, described in Deliverable 5.2 and designed for intra-day optimization and real-time corrections in Energy Communities, has been adapted as the primary control logic for real-world operations. Several tests have been performed for validating and improving the control logic through a one-week optimization time horizon. The parameters set for the two sites are shown in Table 1.

Table 1. Configuration of Locations in the Virtual Model

Charging units specifications

Location	Nominal power	Charger type	Current type	Land
Moving Lab	$[22;\ 22;\ 11]\ kW$	V2G; V2G; V1G	DC; DC; AC	Private Area
Design Campus	$[22;\ 22;\ 11]\ kW$	V2G; V2G; V1G	DC; DC; AC	Public Area
Moving Lab management units				

PV	Peak power	100	kW
	Azimuth angle	$20°$ West	
	Tilt angle	$20°$	
BESS	Capacity	100	kWh
	Max charging rate	1.5	$1/h$
	Max discharging rate	2	$1/h$
Moving Lab power demand			

The PV peak power and BESS capacity have been scaled-up to match building energy consumption, exceeding the specifications of the real-world case study. This approach highlights the potential benefits achievable with higher investment costs. The integration of BESS enhances energy management in conjunction with EVs within the parking area. Unlike the conventional $3\ kWh{:}\ 1\ kWp$ pairing of PV systems with BESS, a reduced $1\ kWh{:}\ 1\ kWp$ ratio was adopted to explore a hybrid modulation strategy leveraging both BESS and vehicle flexibility.

To assess the impact of smart charging technologies and BESS on the descripted case study, some scenarios are analysed:

- **Realistic (mixed) scenario:** This scenario includes a variety of users with differing levels of flexibility, influenced by factors such as location and time of day. User behaviour patterns, including vehicle access and charging preferences, were modelled to reflect realistic trends. In the future, these patterns can be refined through training on real-world data tailored to specific parking areas.

- **V1G ideal Scenario:** All users allow for unidirectional smart charging flexibility.

- **V2G ideal Scenario:** All users allow for bidirectional charging flexibility.

Results are compared with two uncontrolled scenarios, which exclude the implementation of BESS and rely on regular constant charging:

- **Priority 1 Scenario:** A hypothetical scenario where the same vehicles and load as in V1G and V2G scenarios are applied, but without any optimization. This serves as a baseline to assess the effectiveness of smart charging technologies.

- **Priority 2 Scenario:** All users are prioritized and always have access to a free charging point. This serves for assessing the reduction of number of vehicles served and the potential decrease in total energy consumption.

The charging schedules for flexible vehicles are tailored to user-defined constraints, such as final SOC and estimated resting time. Meanwhile, the BESS power flow scheduling ensures optimal energy management when vehicles are absent or have limited remaining flexibility. This process is highlighted in Figure 11a, which compares the load supplied and demanded by vehicles and BESS with PV production and building demand in the V2G scenario, while Figure 11b presents the overall net power exchanged with the grid.

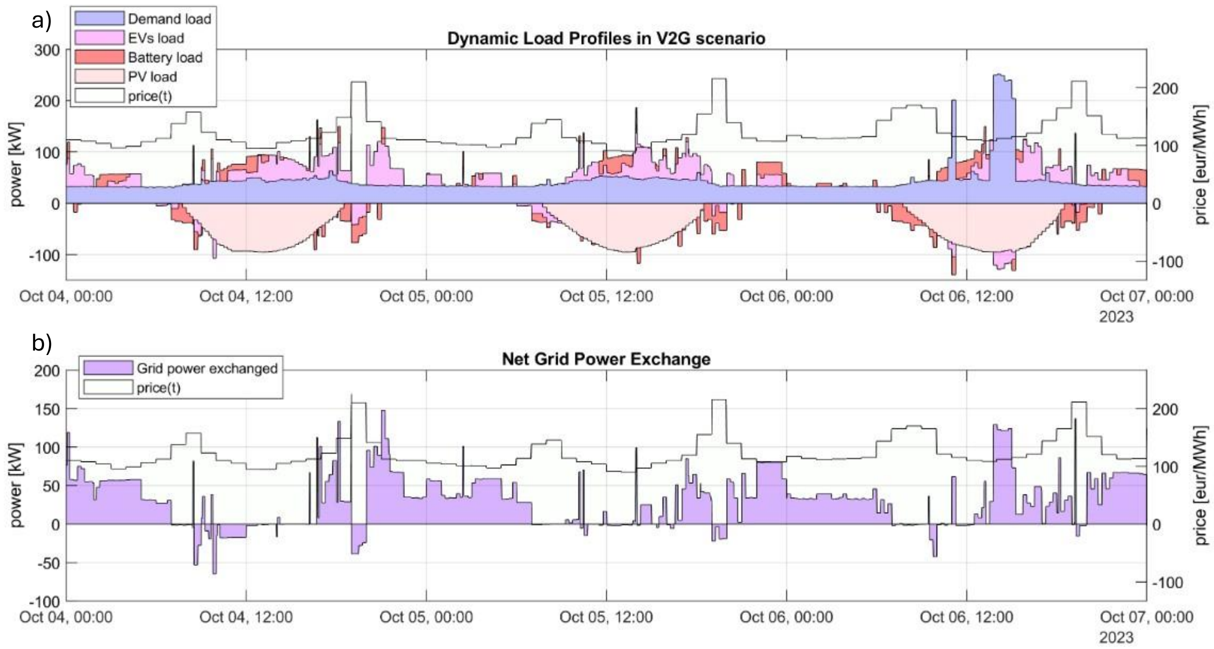


Figure 11. V2G scenario: a) Loads supplied by vehicles and BESS compared to uncontrollable PV and Building load, and alongside the energy price profile. This highlights how the two management systems complement each other in the optimization process; b) Net global grid power exchange.

The optimization process is guided by penalty functions that incentivize specific objectives, such as peak shaving, reducing net energy exchanges, and aligning trading activities with the day-ahead zonal price. In particularly, market trading actions justify smaller-scale optimizations focused on rapid power exchange when other optimization functions remain relatively stable. Figure 12 provides a detailed comparison of the various loads across the five scenarios: V1G Scenario demonstrate effective balancing of flexible loads with PV production, while V2G Scenario can balance loads through controlled discharges, with vehicle discharges being less frequent than BESS discharges. Mixed Scenario shows reduced overall load flexibility compared to V1G and V2G, but still achieves a good alignment with PV production. Unoptimized

Scenarios shows more imbalanced load profile; this issue is even more pronounced in the Priority 2 Scenario, which features a high number of charger accesses.

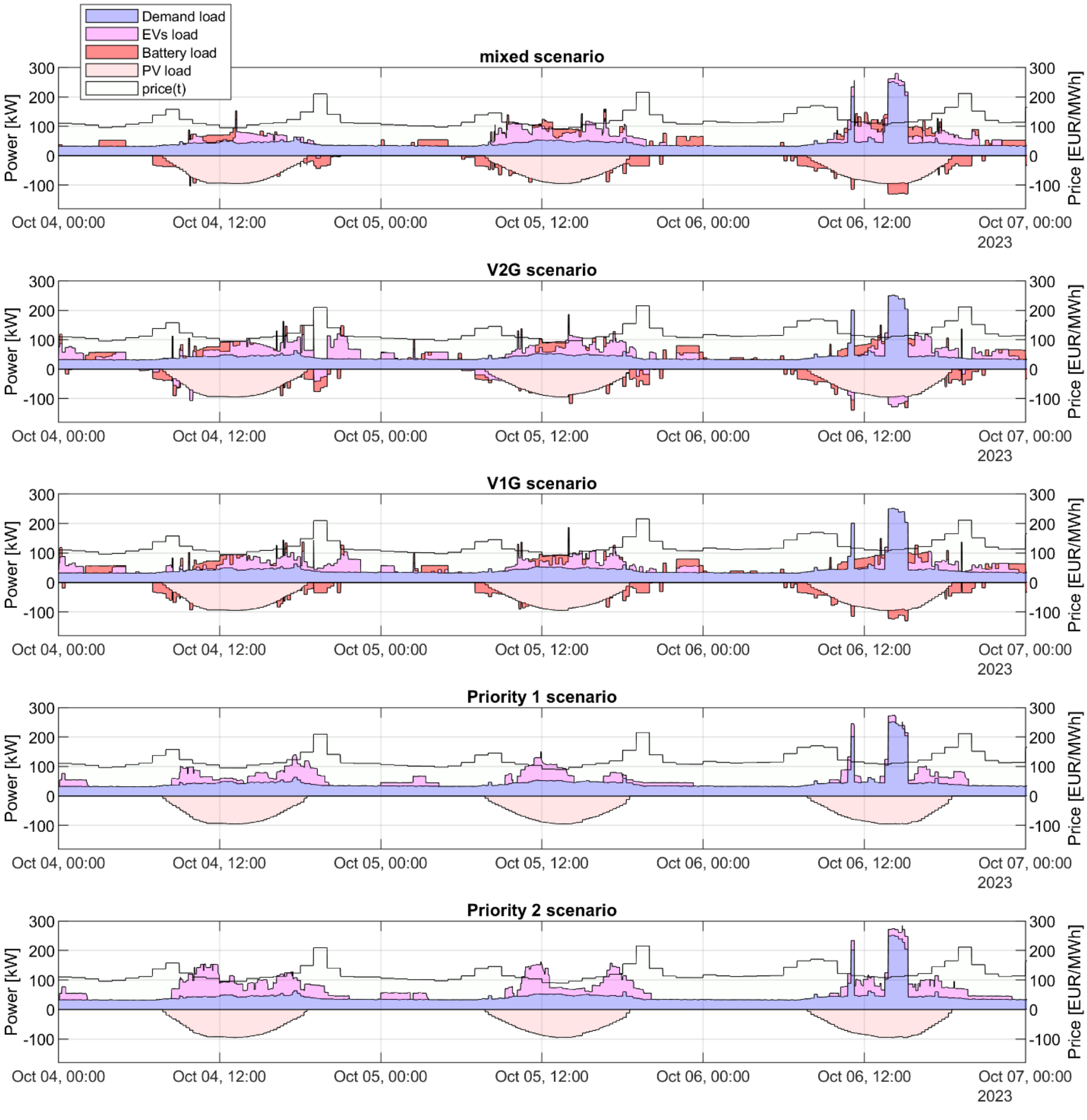


Figure 12. Simulated results over a 3-day time span, comparing EV power consumption across the five scenarios.

A hybrid approach combining BESS and smart charging technologies proves effective in reducing the total energy exchanged with the grid and aligning consumption with local PV production, as shown in Figure 13.

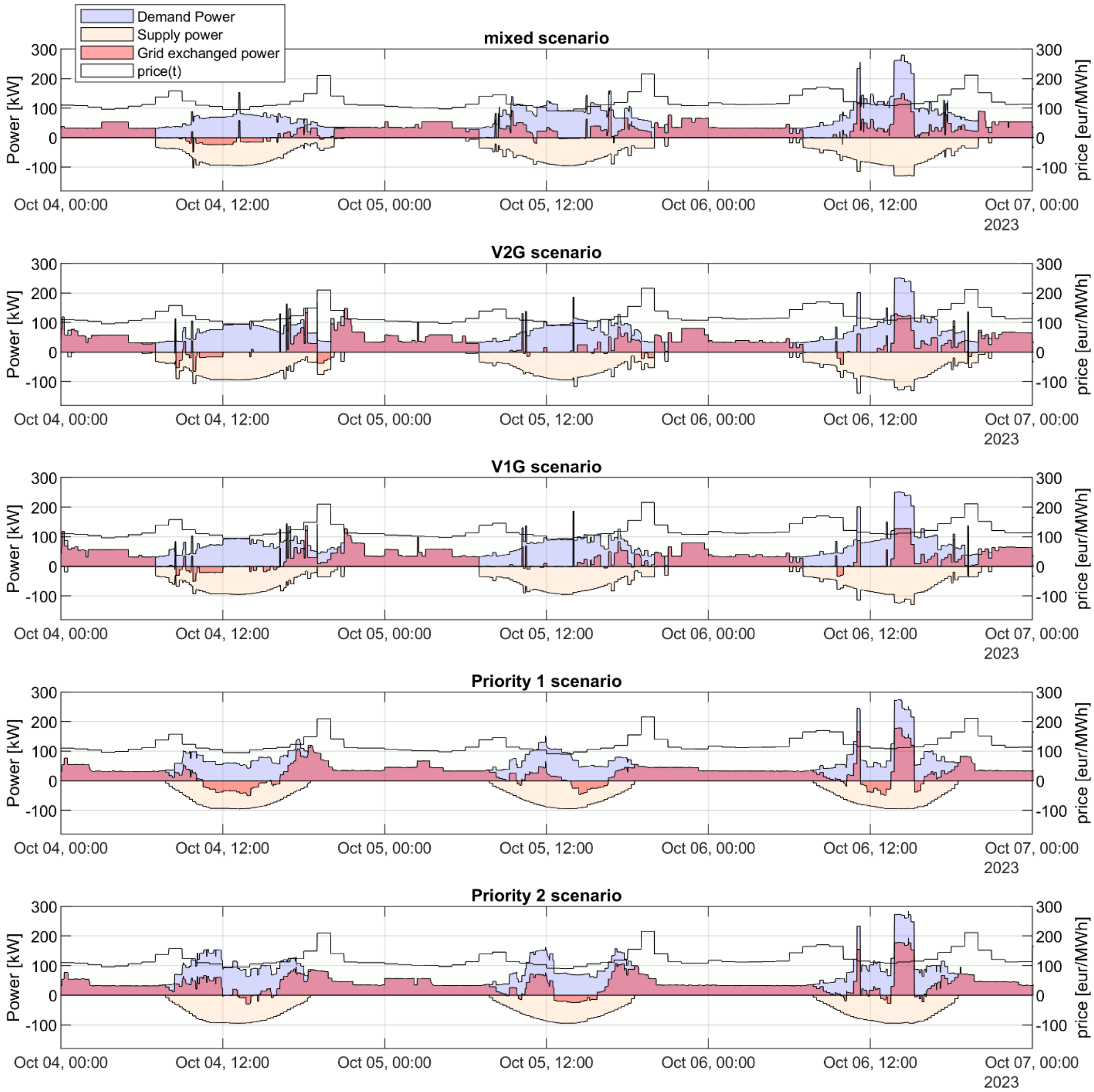


Figure 13: Simulated results over a 3-day time span, comparing demand, supply and net exchanged power across the five scenarios.

A realistic scenario involving both flexible and priority users shows similar results compared to scenarios with full user flexibility (V2G/V1G), but achieves a higher number of vehicles served, due to the reduced resting time per vehicle. This result highlights how increased user flexibility can potentially reduce the service provided per charging station and the average power delivered. Consequently, parks with flexible charging require a greater number of stations compared to standard parks to ensure sufficient energy demand, which is necessary to achieve the benefits of load modulation. Figure 14 presents a comparison of the following KPIs:

- **Mean energy cost**: defined as the average price of energy purchased from the grid. It reflects the control logic's ability to trade energy based on price, leading to potential cost reduction and alignment with grid requirements.

- **Total energy exchanged**: calculated as $EN_{grid} = \int_{t0}^{tf} |P_{grid}(t)| dt$.
- **Vehicle served per day**: it evaluates the potential impact of increased user flexibility on the total charging service provided.

In addition, the utilization of local Renewable Energy Sources (RES) is assessed using two primary indicators:

- Self RES consumption: This measures the capacity to consume locally generated renewable energy (PV_{self}), in respect to the total energy produced ($PV_{produced}$); It is defined as:

$$\int \frac{PV_{self}}{PV_{produced}} dt$$

- RES to cover demand: This indicates the capability of the renewable plant to meet community power demand (P_{demand}); It is defined as:

$$\frac{\int PV_{self} dt}{\int P_{demand}\, dt}$$

KPIs' comparison highlights a significant increase in the utilization of local RES in scenarios with flexible users, but also a notable reduction in the charging service provided; Therefore, smart charging technologies must be carefully assessed for charging stations located on public grounds, while they appear more suitable for private use, such as V2H or V2B with large vehicle fleets. Mixed scenario demonstrates promising results, achieving values similar to fully controlled scenarios while serving a greater number of vehicles. This is attributed to the BESS's ability to partially meet the priority demands of high-requirement users.

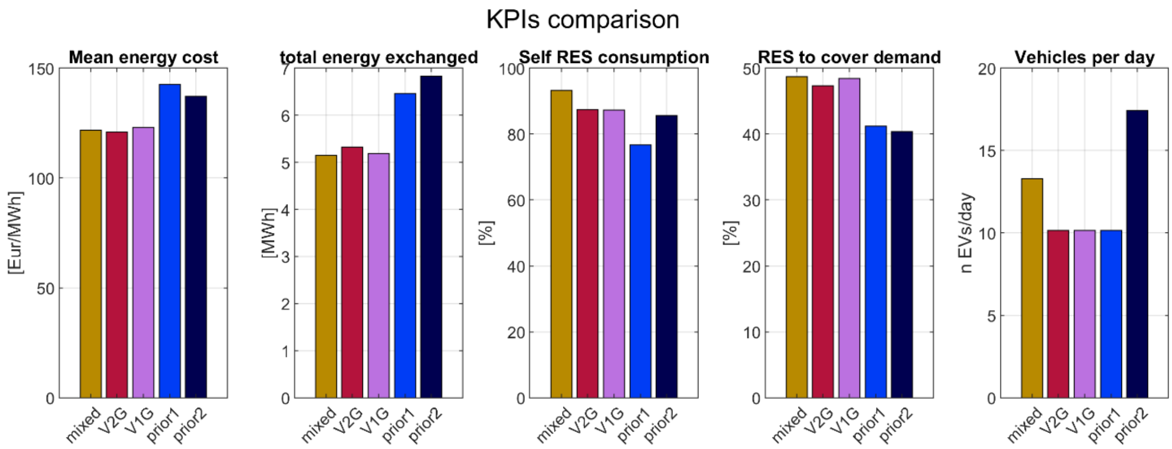


Figure 14. Comparison of KPIs for the different scenarios.

Figure 15 highlights how the average power across different time slots contrasts more closely with the price trend in the optimized scenarios. This result demonstrates not only potential cost savings but also the system's ability to adapt consumption to local grid congestion.

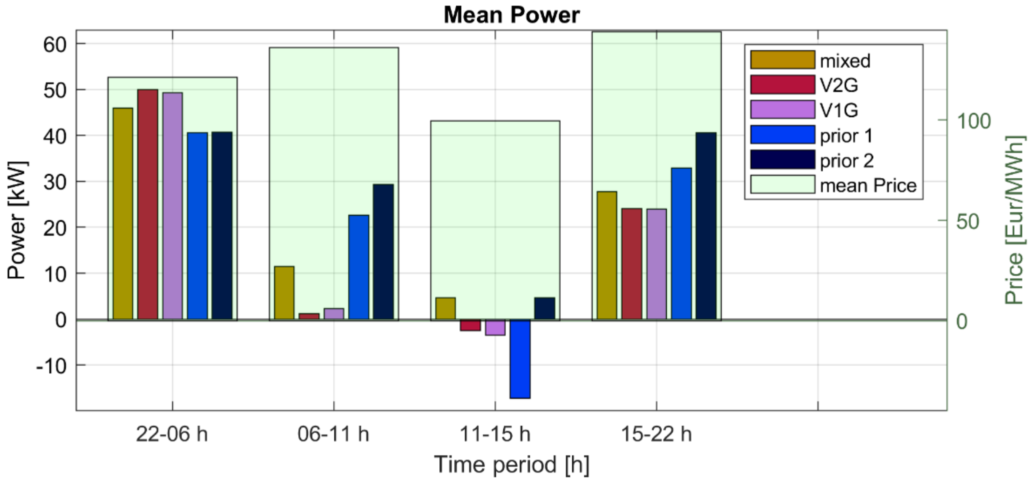


Figure 15. Comparison of average power consumption by time slot, relative to mean energy prices.

A critical analysis will be conducted by comparing the potential results with real-world outcomes. This will allow for an evaluation of system performance against expectations, considering both differences in scaling and variations in user behaviour.

4.2 System Setup

The system setup for the two sites, **MOVING LAB** and **CAMPUS DESIGN**, follows a phased approach aimed at creating an energy management system with modularity and scalability. Based on the hardware specifications and operational requirements outlined, the following detailed description provides insight into the planned installation and its associated phases.

For the **MOVING LAB**, this site will integrate a photovoltaic carport designed to accommodate two parking spaces, as shown in the Figure 16. This system is entirely modular and mounted on ballast or poles, with no invasive foundations. The expected solar power capacity is approximately 5–6 kWp, based on the space available and system efficiency.

Figure 16. Installation area of the MOVING LAB site.

The key system components include:

1. **Photovoltaic Carport**. A lightweight carport structure equipped with solar panels that act as the primary source of renewable energy. The carport also integrates a Maximum Power Point Tracker and a three-phase inverter capable of providing up to 11 kW of output, with a minimum capacity of 7–9 kW acceptable.

2. **Energy Storage System**. A static battery storage system with a capacity of approximately 10–15 kWh. This storage unit will enable power availability during periods of low solar generation and will be mounted on the ground in a non-invasive manner.

3. **Electric Vehicle Charging Infrastructure**.

    a. Phase 1 (**Standalone Mode**): A single Type 2 AC charging point with a power output of 11 kW. The charger is directly integrated with the carport and will implement V1G smart charging flexibility with BESS and PV as a standalone system.

    b. Phase 2 (**Extended Mode**): The addition of 2 DC charging points installed on portable stands. These stands will host the chargers provided by Circontrol as part of the project's technical partnership. The site will be connected to the electric grid of the laboratory building and the CAMPUS DESIGN site to implement the already discussed control logic.

4. **Energy Monitoring and Control.** The system will feature advanced monitoring and communication capabilities, including Modbus, Ethernet, or CANbus interfaces, to facilitate real-time data acquisition and dynamic power control. Operators will have the ability to manage the energy flows between the solar panels, battery storage, and charging points. This includes functions such as

battery charging while consuming grid power, disabling battery output, or temporarily halting the system's operation. The measurements will be carried out by smart power meter supplied by a UNIFI spinoff “PowerEMP”, designed to detect power quality anomalies.

5. **Future Grid Connection.** While the **MOVING LAB** system is designed to operate in standalone mode or island configuration, it will include provisions for connection to the electrical grid. This will involve a pre-wired connection point for integration with the “Enel Distribuzione” three-phase power network.

The simplified electrical scheme and the communication scheme are shown in Figure 17 and Figure 18. The simplified electrical scheme outlines the core components and connections of the system, which has been prepared for suppliers. It features an existing three-phase power supply with a digital meter and the integration of the **MOVING LAB** building. The system connects to the demonstrator unit, which can operate either as **Standalone Mode** or **Extended Mode**, depending on the configuration of a switch. Key components include the main system inverter, which converts from a DC-BUS (fed by photovoltaic panels and a battery energy storage system, or BESS) to a three-phase system with a typical power output of 11 kW. The photovoltaic cells, mounted on the parking lots, provide approximately 5 kWp of power and are connected to the DC-BUS via a maximum power point tracker (MPPT) DC/DC converter. Additional elements include a single-phase supply for managing the telecommunication systems, a Wallbox for Type 2 AC charging, and three-phase plugs for additional chargers or DC systems to be installed after the main electric panel. A dedicated three-phase charger manages the battery state of charge (SOC) independently from photovoltaic production. The BESS serves as the key storage system, enabling efficient energy use and providing flexibility to the system.

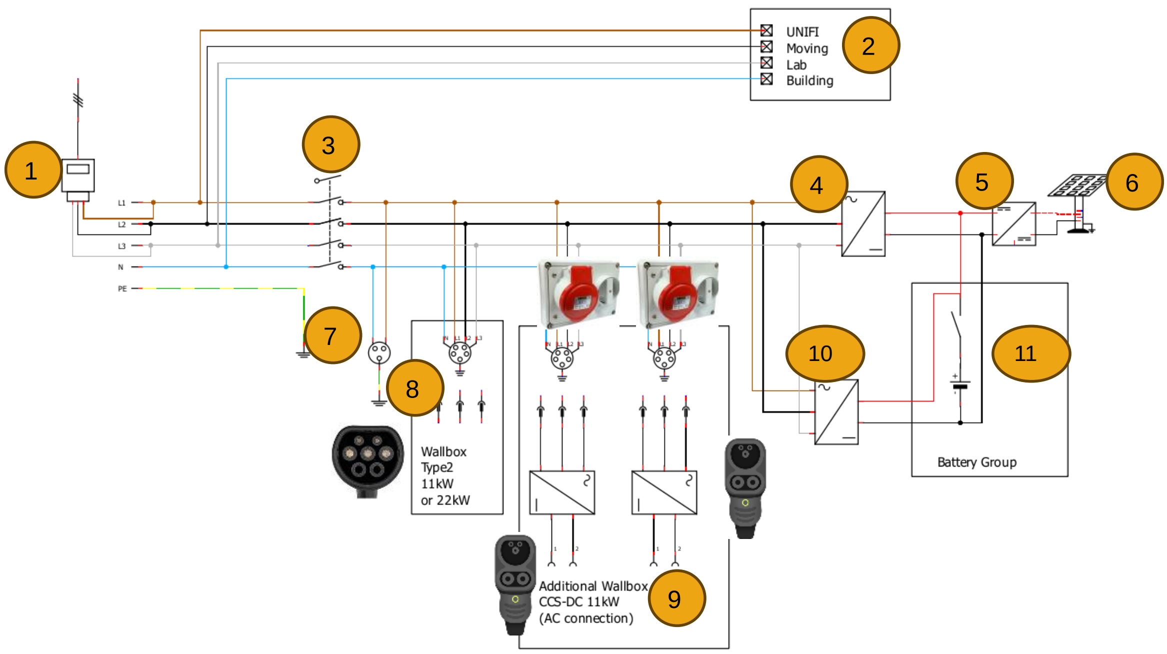


Figure 17. Simplified scheme and components installed in the MOVING LAB demonstration site.

The communication scheme, instead, illustrates how the system components are integrated through a centralized cloud server, which enables seamless data exchange and control. The Users' App allows end-users to interact with the system, monitor energy consumption, and manage EV charging activities via the cloud server. External inputs, such as day-ahead energy prices and photovoltaic power forecasts, are connected to the system through Web APIs, providing crucial data for optimizing operations and scheduling energy flows. The public chargers, connected via Ethernet, allow centralized control and management of the EV charging infrastructure. Measured data from various system components—including the building, chargers, photovoltaic system, BESS, and inverters—are transmitted in real time using communication protocols like CAN BUS/TCP or OCPP. The smart power meter and gateway enable accurate monitoring and control of energy flows between the grid, the building, and renewable energy components. The **MOVING LAB** integrates multiple subcomponents, including the building, chargers, photovoltaic system, battery energy storage system, and inverters. This design ensures interoperability, with the cloud server coordinating the real-time exchange of data and optimizing the interaction between the system components. The use of industry-standard protocols such as MQTT and OCPP ensures that the system can efficiently manage the energy resources in a scalable and flexible manner. Together, the electrical and communication schemes demonstrate a comprehensive system design that balances flexibility, scalability, and efficiency, prepared for diverse real-world applications.

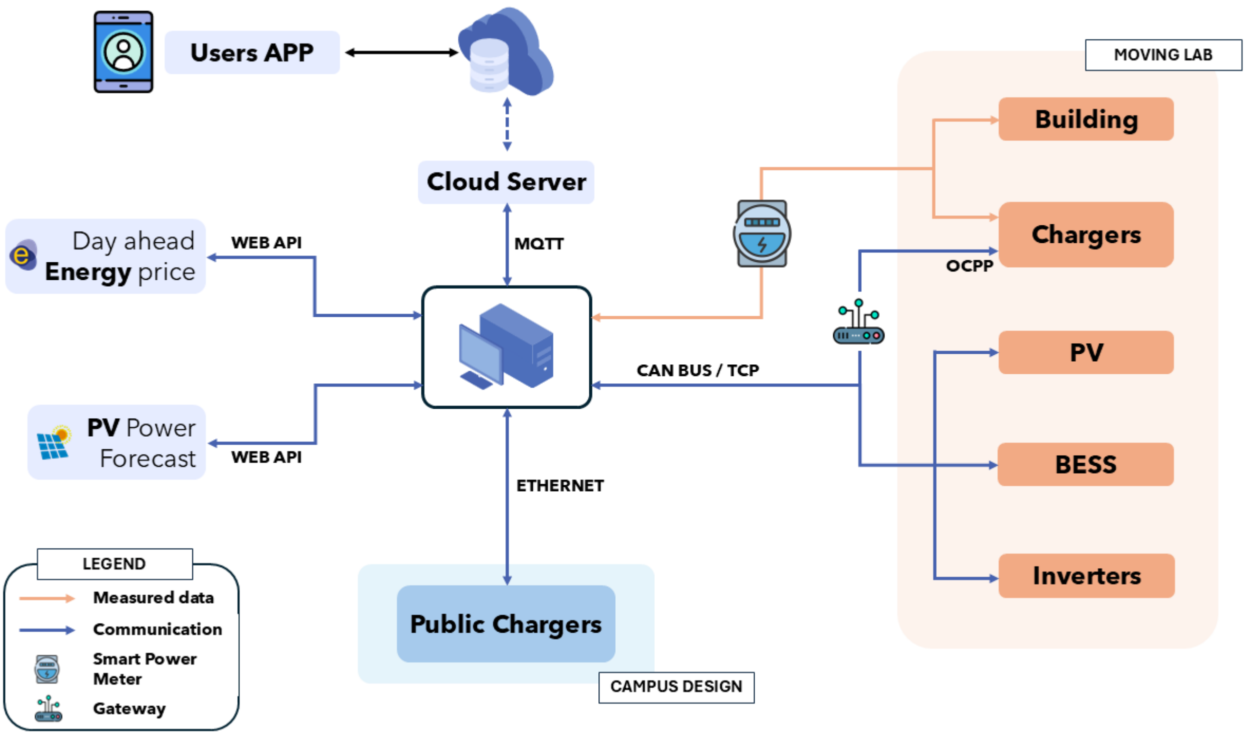


Figure 18. MOVING LAB communication scheme.

For the **CAMPUS DESIGN**, this site will leverage pre-installed infrastructure while implementing advanced energy management strategies. The site includes:

1. **Existing Charging Points**. 3 Charging Points are already installed and operational charging points provided by a local partner will be integrated into the demonstrator. These stations offer access for public use by both the community and university members. The integration means that the real-time data will be provided to the management system, in order to start-up mitigation operation to reduce the overall grid impact, as described. However, no control of the public charging station is planned at the moment, so they will proceed without influencing users' experience, since chargers are adopted for commercial services.

2. **Energy Management System**. The demonstrator will utilize a centralized control system to manage energy flows efficiently across the three charging points, optimizing grid impact, and incorporating photovoltaic power when available. The power control will be implemented through remote monitoring and management. The system will actively monitor the power absorbed by **CAMPUS DESIGN** and **MOVING LAB** systems, ensuring a balanced and efficient energy distribution. This will be achieved by leveraging the centralized computer hub, which collects real-time energy consumption data from both the **CAMPUS DESIGN** public chargers and the **MOVING LAB**'s energy-intensive facilities. The hub will process this information to implement a control logic that dynamically adjusts the power absorbed by each site, based on current demand, energy availability, and predefined thresholds. This integrated control approach will not only optimize the energy usage across the two locations but will also ensure that both systems operate within their capacity limits, reducing stress on the grid and maximizing the utilization of renewable energy sources like photovoltaic systems and battery storage. The flexibility of this solution also enables adjustments to power distribution in response to variations in solar energy generation or fluctuations in EV charging demands.

3. **Scalability and Public Accessibility.** The project highlights its compatibility with future upgrades, ensuring that additional chargers or renewable energy sources can be integrated seamlessly.

A note is necessary regarding the expansion of the system using bidirectional, DC chargers. For the case of Italy, not only the availability of CCS-V2G hardware is limited, similarly to all European case studies, but there are additional limitations in the adoption of hardware comparable to other case studies (e.g. AMBIBOX device, as in the Aachen demonstration action). This is due to the need to satisfy the Italian technical rule CEI 0-21;V2 [2](latest version: January 2024), "Reference technical rules for the connection of active and passive users to the LV electrical Utilities", for which recent products are still not certified. The mitigation action proposed by the University of Florence is based on two points:

[2] https://static.ceinorme.it/strumenti-online/doc/20207.pdf

- The system is ready to accept additional charging points as soon as they will be available, installing three-phase plugs, 32A, available directly on the PV management board

- In case that pre-series device will be provided for the installation (e.g. from ABB or CIRCONTROL partners), an additional monitoring device will be added, to verify the correspondence of the exchanged power with CEI 0-21 requirements. Such devices will be either commercial units[3] or specific unites provided by a local company expert in grid power quality management[4], which will be included in the demonstrator as supplier.

4.2.1 Early Data Collection – Calenzano Area

On December 2024, the ESTRA partner provided access to their charging units, which are included in the area close to **DESIGN CAMPUS** and can be monitored with a limited time delay (approximately 3-4 minutes), thus providing an efficient monitoring tool.

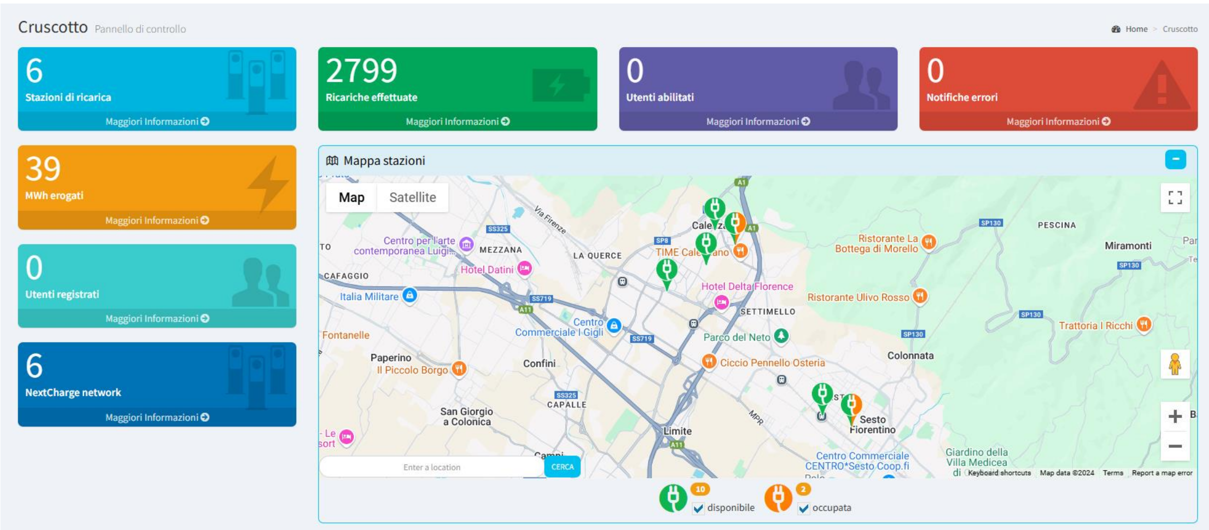


Figure 19. Control Dashboard for charging stations.

The units under monitoring include:

(1) Station 1, Calenzano “Bordoni”, which is servicing directly the **DESIGN CAMPUS** units, being located exactly on the parking lot close to the University building.

(2) Station 2, Calenzano “Fogliaia” (walking distance to **DESIGN CAMPUS**: 1.0 km)

[3] Protection interface ABB CM-UFD.M22M - https://library.e.abb.com/public/5c6c7a39f062456cb801fae3f6e7f063/1SDC112001L0906.pdf

[4] https://www.poweremp.it/

(3) Station 3, Calenzano “Puccini” (walking distance to **DESIGN CAMPUS**: 0.7km)

(4) Station 4, Calenzano “Ungaretti” (walking distance to **DESIGN CAMPUS**: 1.1 km)

Each station includes 2x 22kW AC plugs, for a total of 8 plugs under monitoring and a peak power of 176kW, which is in practice rare to see due to the fact that most AC “on board chargers” typically use 11kW. All these stations are suitable for inclusion in the Calenzano-based renewable energy community, being inside the border of the homogeneous area. For comparison purposes, also the charging stations installed in the close municipality of “Sesto Fiorentino” are included, achieving a total of 6 stations monitored. The data refers to the charging station only, and it is not possible to associate the event with user or vehicle class. An early data balance is provided on Table 2.

Further data will be obtained during 2025 demonstration action. A few notes can be observed according on the sizing of the demonstration site which is installed in the **MOVING LAB** and which will act with power modulation and power injection (through the BESS), optimizing the total energy exchange of the whole location:

- PV sizing: the energy exchange per day is estimated to be below 30kWh in the Calenzano area. A PV system capable of 5kWp is expected to provide an average value of 20kWh/day, in optimal condition, in Italy. This means that the daily production, at this level, is comparable to the average consumption. Such values appear to be quite limited and are probably motivated by the limited penetration of EVs in Italy.

- Charge effort: even if the maximum station power is 22kW per plug, average power is below 5kW. Certain events show a power below 3kW, which is probably related to the charging of small size EVs, such as quadricycles, which typically rely on single phase chargers. Again, this limited power confirms the potential efficacy of the demonstration lab to compensate for this type of charging event.

- BESS sizing: the planned energy storage, emulating a V2G unit, has a capacity of above 10kWh: this energy, coordinated with PV production, can support charging events maintaining the average power (below 5kW, as said) for an equivalent time of more than 2 hours.

- Charge duration: the structure of charge duration is significantly different if Calenzano only or Calenzano and Sesto are monitored; knowing the origin of the data, charging stations in Sesto are located in parking lots having frequent exchange, probably motivating the existence of small-duration events. Considering the municipality of Calenzano, the typical duration (8hours) and the low resulting average power (2.9 kW) is compatible with management strategies aimed at reducing peak power and enhancing self-consumption, thus reducing total grid exchange at the borders of the virtual energy community.

- Data availability: through a proper exchange tool, the data provided by the monitoring system are suitable for inclusion in the data exchange system designed for the demonstration, as shown in Figure 18.

Table 2. Data from municipal charging stations. Period September – December 2024.

Data	Unit	Calenzano and Sesto	Calenzano only
Plugs	Number	12	8
Period duration	Days	78	78
Event number	Number	261	89
Event density	Events/Day	3.3	1.1
Average event duration	Hours	4.3	8.1
Total charging time	Hours	1065.6	718.2
Total energy	kWh	4733.1	2070.2
Average charging power	kW	4.4	2.9
Average Energy per day	kWh/day	60.7	26.5

4.3 Outlook and Risks

As already mentioned in the presentation section, the demonstration is currently progressing with the setup of the **MOVING LAB** and **CAMPUS DESIGN** sites and the implementation of the control logic. By the end of 2025, the **MOVING LAB** will be in operation, firstly in **Stand Alone** mode and next, with different accords with local partners, in **Extended Mode**. The control logic explained above is fully working and will be integrated with a smart power meter for the real time measurements. In the light of this, a risk and mitigation measures list are provided below.

<u>Risks:</u>

1. Bureaucratic or logistical challenges may delay the final setup of the **MOVING LAB** and **CAMPUS DESIGN** sites, affecting the timeline for the demonstrations.

2. Limited knowledge of protocol communication and local grid certification needs for V2G in Italy

3. Limitations for the extended mode operation of the **MOVING LAB**, in term of consumers privacy, so that control of public charging points is not going to be applied.

    a. On the other hand, such point guarantees that the provided solutions are mitigating the impact due to the energy management in the private area, while having no impact on the commercial service, thus guaranteeing the acceptance by the existing users.

4. Issues may arise during the implementation and testing of the control logic, affecting the accuracy of the data or the performance of the system.

5. The transition from standalone to extended mode may introduce unforeseen operational risks, such as grid instability.

Mitigation Measures:

1. Close collaboration with university authorities to expedite necessary approvals and parallel progress on preparatory activities such as software development and testing.
2. If no protocol communication for V2G will be available in Italy, the V2G charging action will be emulated by other system equipment (like BESS and PV). The BESS will be used in order to be totally comparable with V2G-enabled cars, ensuring a power level of at least 7kW.
3. Different local providers have been contacted to maximize the possibility to obtain the management of existing CPs in the Calenzano municipality. In the worst case if only **Stand Alone** mode is functional, the **Extended Mode** will be simulated using the control logic.
4. To minimize the risk of control logic malfunctions, comprehensive testing will be carried out before full-scale implementation, including stress testing in real-world scenarios.
5. A gradual and phased approach will be implemented for the transition from **Stand Alone** to **Extended Mode**, with continuous monitoring of grid stability. Simulation models will be used to predict and mitigate potential grid impacts, and the transition will be tested in small, controlled steps to address any instability early.

5 ABB Demonstration

The European energy sector is moving toward a significant expansion of renewable energy sources to meet the ambitious renewable energy goals set by the European Commission in 2023. In this context, the advancement and deployment of microgrids powered by renewable energy can accelerate the transition, supporting the integration of renewable resources, improving the resilience of the power grid and minimizing inefficiencies by bringing energy production and consumption into closer alignment. The primary contribution provided by ABB for XL-Connect project is the creation of a demonstrator at ABB's facility in San Giovanni, which will be one of the first of its kind, see Figure 20. This microgrid system will be fully integrated with several components including a photovoltaic (PV) solar array, a battery energy storage system (BESS), and both ABB's bi-directional V2G DC and mono-directional chargers. This innovative charging technology is designed to support smarter energy management as to increase self-consumption, DER’s blending and leading to enhanced connectivity and greater cost efficiency; in addition, these technologies aim to support users and communities in transitioning to electric mobility and maximizing its potential.

Figure 20. ABB demonstration general system set up.

The microgrid is designed to operate in two distinct modes (cf. Figure 20): islanding mode (off-grid) and grid connected mode (on-grid):

- In islanding mode, it operates independently, relying solely on its photovoltaic (PV) system, energy storage, and charging infrastructure to meet the demand of its local loads, including EV charging and other connected systems.
- In grid-connected mode, the microgrid links to the main grid for optimal energy management, allowing it to supply surplus energy back to the grid or draw additional power when necessary.

This dual capability ensures efficient energy flow management, maximizing user satisfaction by adapting to the operational mode. ABB E-mobility's microgrid has been implemented as a demonstrative use case with some specific goals:

1. **Development of Bidirectional DC Chargers (**Figure 21. Bidirectional DC Chargers : ABB E-mobility is set to design and manufacture an advanced bidirectional DC charger for a real-world demonstration at its Valdarno production facility. For this project, ABB has selected a specific V2G-capable charger from its portfolio and customized it to meet the latest V2G standards for road vehicles, including compliance with the ISO 15118-20 vehicle-to-grid communication interface. The charger will also feature a CCS connector, switching from the original CHAdeMO, to support seamless integration with EU market electric vehicles. As it shown in Figure 21 the V2G chargers should work as bridge between the grid and the EVs users as to meet the energy transition and DER's blending trend with the mobility transition.
    a. Assess the grid stability when implementing the V2G technology, both in grid-connected mode and off-grid mode.
    b. Evaluate new V2G chargers and collect data from their use to improve the product.

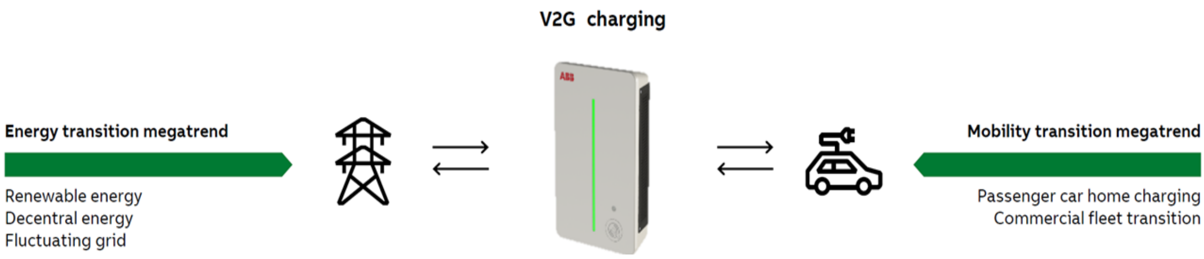


Figure 21. Bidirectional DC Chargers

2. **Optimization of Microgrid Power and Energy Flows**: In addition, ABB E-mobility will create a solution to optimize power and energy flow management within the microgrid, ensuring maximum efficiency and smart operation. This effort will focus on addressing critical challenges such as grid stability and load balancing.
   The optimization process will run in parallel with the physical construction and will leverage a virtual microgrid model, along with an initial static model, to simulate the operation and performance of the energy management system. These simulations will provide a robust foundation for fine-tuning energy flow optimization during future on-site implementation.
    a. Maximize the consumption of on-site produced renewable electricity (Goal of the simulation proposed below).

b. Optimize the energy and power flows to benefit from flexibility strategies, such as Load levelling, Peak Shaving, Priority Recharge (Goal of the future on-site optimization).

5.1 System Setup

The microgrid will be physically located across the two front parking lots of the plant, a space that offers several advantages for its installation. Notably, this area already houses an operating photovoltaic (PV) system, has a designated area for the Battery Energy Storage System (BESS), and includes existing charging infrastructure, making it an ideal site for the microgrid deployment. In addition, there's a parking lot dedicated to heavy duty vehicles equipped with high power chargers, designed for high power recharge. Most of the underground infrastructure (i.e. the cables) already flows underground in that area and just its terminal part needs therefore to be redirected from the plant's cabinet to the new microgrid's cabinet. These pre-existing assets not only reduce installation time but also ensure that the required infrastructure is in place for seamless integration of the microgrid components. For details see Figure 22.

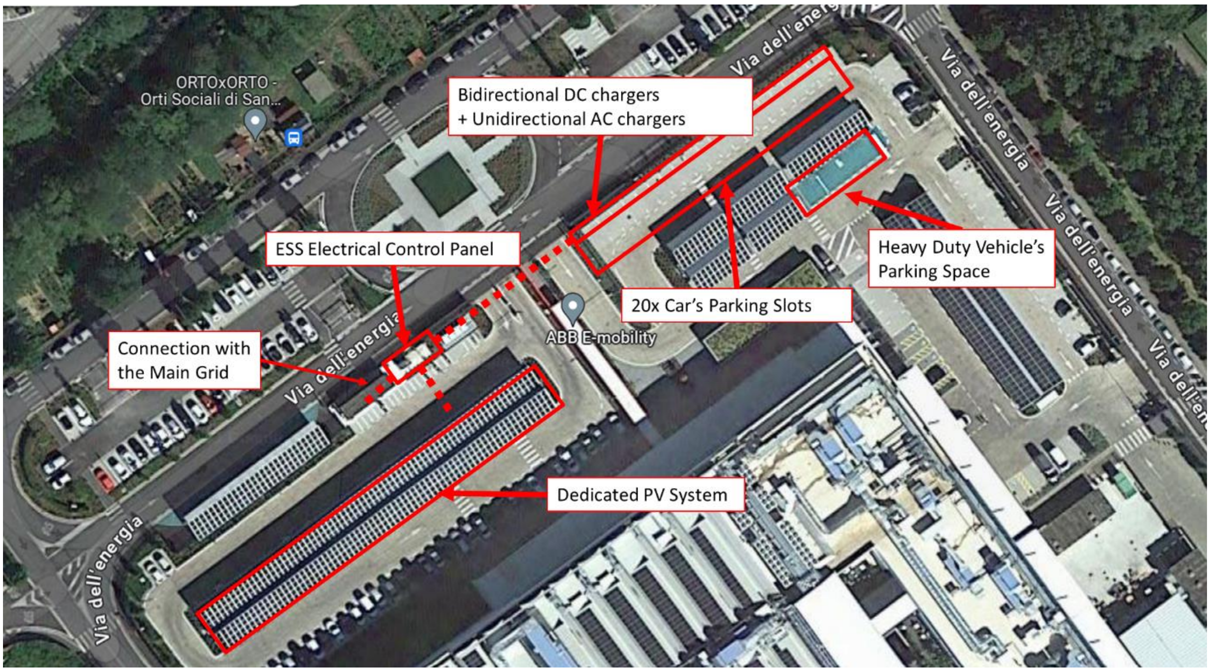


Figure 22. ABB System Setup

The microgrid will be composed of four primary elements: a 130 kWp photovoltaic system, a 189 kWh / 100 kW Battery Energy Storage System (BESS), seven bidirectional DC chargers rated at 11 kW each, and ten monodirectional AC chargers rated at 22 kW each. The PV system will generate renewable electricity, which will either be consumed locally or stored in the BESS. The bidirectional DC chargers will enable Vehicle-to-Grid (V2G) interactions, allowing the electric vehicles (EVs) to both charge and discharge energy, depending on grid requirements or users demand, while the monodirectional AC chargers will provide conventional EV charging. Together, these components will work to optimize the energy flow, ensuring efficient charging, storage, and distribution of power. This mixed charger installation solution will allow to connect almost every EVs as to be ready to future OEM’s, offering a large span of charging socket types. The management and coordination of power flows between these elements will be supervised by a grid controller; it will regulate how energy is distributed among the various components, ensuring that the microgrid operates efficiently and in alignment with the overall system's objectives. The controller will manage the integration of energy from the PV system, manage the energy storage in the BESS, and optimize the charging and discharging cycles of the electric vehicles, depending on real-time needs and the availability of renewable energy.

5.1.1 Components: Detailed Description

To build up such a microgrid, several components must be taken into consideration and each of them are required to meet technical constraints as well as time and cost limitations dictated by the project's budget and schedule. To achieve these goals ABB takes charge of internally developing chargers equipped with V2G CCS and, parallelly, seeking a suitable Battery Energy Storage System (BESS) on the market. Meanwhile, the project designer drafts a preliminary technical layout of the microgrid, ensuring the components' topology aligns with grid requirements.

5.1.1.1 Mono and Bidirectional Chargers

One of the primary objectives of XL-Connect is to evaluate V2G technologies, making the bidirectional chargers the centrepiece of the microgrid. They are the only loads linked to the microgrid, with the monodirectional chargers acting as pure loads and the bidirectional that can be considered both as loads and sources of energy (cf. Figure 23). Chargers are not considered primary loads, so they do not require backup power and can tolerate brief interruptions in energy supply. This detail primarily impacts the behaviour of the ON-OFF grid switch transition, resulting in a less strict constraint on switching time.

Figure 23. Mono and Bidirectional chargers

Valdarno's microgrid will host 6 classic monodirectional chargers, the 22 kW Terra AC Wall box and 10 bidirectional chargers, the 11 kW DC Terra Nova 11J and also High-Power Chargers for Heavy Duty Vehicles, Figure 23.

- **Terra AC Wall box**: The Terra AC Wall boxes are designed for installation in locations where vehicles remain parked for extended periods, such as homes, workplaces, retail centres, and hospitality venues. These AC destination chargers offer a broad range of power outputs, making them adaptable to various use cases depending on the chosen Wall box configuration. For instance, at home, where vehicles are typically parked overnight or for extended durations, lower power outputs are sufficient for a full charge. Conversely, at workplaces or other facilities where vehicles are parked for shorter periods, higher power outputs can expedite the charging process. Up to 10 Terra AC 22kW Wall boxes that are already installed onsite are redirected to the microgrid and will used in it.

- **DC Wall box**: In the context of this microgrid, the Terra Nova 11J play the fundamental role of virtually turning the connected vehicles into energy storage systems: the battery of an electric car can be used to store electricity when the demand is lower than the onsite renewable production, to use it during peak hours. This solution brings many advantages also in the microgrid's design phase: first of all, the sizing of the BESS can be conducted also considering solutions having a lower capacity than the actual expected loads' demand, as cars can contribute to fulfil this demand, achieving economic benefits. Secondly, cars can support the BESS during peak of power demand to maintain grid stability: if all loads are connected to the microgrid at the same time, the instant power required by them can be higher than the maximum power the BESS can supply, so the cars can give their contribution and help to fulfil the power demand by feeding power into the microgrid and thus maintaining it stable. All these advantages are certainly more interesting when the microgrid operates in islanded mode, since in grid-connected mode the grid will conduct those activities.

- **HVDC Chargers**: This parking area is specifically designed with dedicated spaces for parking and recharging heavy-duty vehicles. The chargers, equipped with CCS technology, will be of the same type as those used for EVs but designed to reach a higher power output values; however, the larger battery capacities of heavy-duty vehicles will result in longer charging times compared to standard electric vehicles, so higher charging power are required. The HVC 360 Cabinet and Depot Box will allow to split power through three outlets, making it suitable for all HDV kind of recharging system; for example, Panto Up will allow to charge bus or truck, equipped with compliant system, and Panto Down and Depot are suitable for all kind of EV's plugs, see Figure 24.

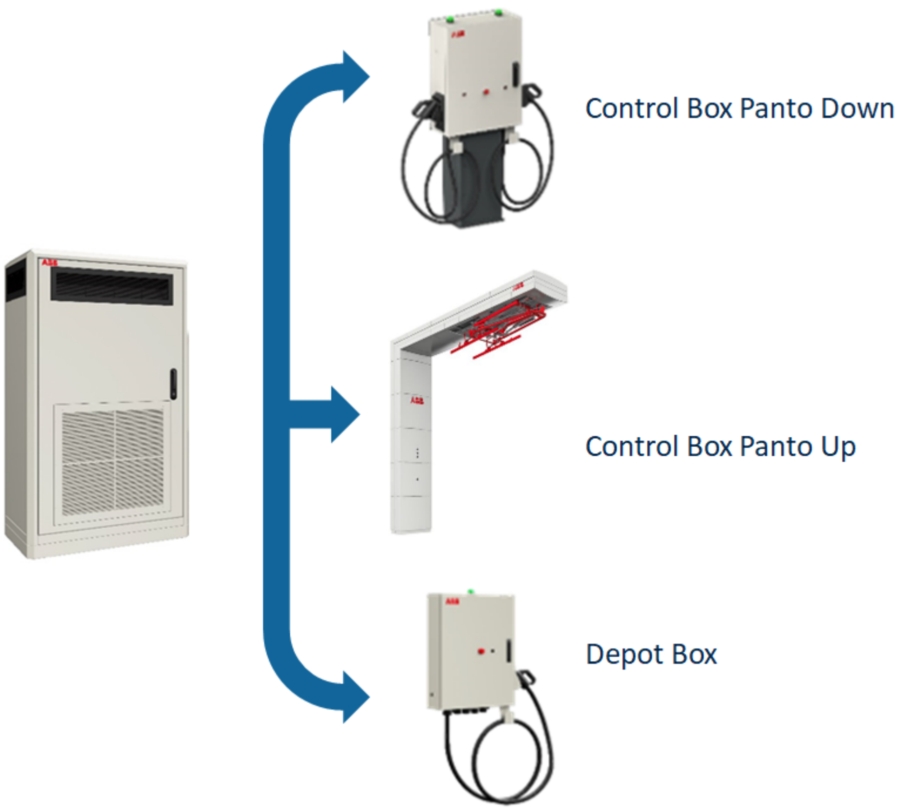


Figure 24. HVDC Chargers

5.1.1.2 Photovoltaic System & PV Inverters

The microgrid's photovoltaic (PV) system consists of 284 Q Cells Q.PEAK DUO 460Wp modules, installed on the roof of a shelter located in one of the plant's parking lots. Table 3 shows the details. The system has been designed with a capacity of 130 kWp, a value determined by segmenting the parking lot's PV array. This approach was chosen to minimize reconfiguration efforts, and costs, while seamlessly integrating this section into the microgrid.

Table 3. PV Characteristics

Model	Q.PEAK DUO XL-G9.3 440-460
Power	460 Wp (for each module)
Dimensions	2163 mm x 1030 mm x 35 mm
Number of Modules	284

The electricity generated by the 130 kWp dedicated solar system is managed by 3 solar inverters, with a size of 30 kW each, for a total of 108 kW. This inverter model has already installed and will be integrated with the BESS as to set communication link suitable for energy management and control. These three-phase inverters are designed for commercial and industrial photovoltaic (PV) systems, offering seamless compatibility with microgrids.

Through communication with both the Point of Common Coupling (PCC) and the Battery Energy Storage System (BESS), they can automatically detect whether the microgrid is operating in on-grid or off-grid mode and adapt accordingly. The solar panels generate direct current (DC), which the inverters convert into alternating current (AC). This AC electricity then flows into the microgrid's distribution cabinet, where it is either supplied to the microgrid's loads or fed into the main grid, depending on the system's requirements.

5.1.1.3 BESS

Selecting the appropriate energy storage system for ABB E-mobility's microgrid is critical, as the system must support islanded operation, effectively functioning as the main grid. Since this is a pilot project, the battery storage size is not strictly constrained by the project's requirements. Instead, it represents a balance between technical capabilities and economic considerations. However, off-grid functionalities are mandatory to meet the objectives of XL CONNECT, making it essential for the storage solution to reliably support this capability. Initially, the Huawei LUNA2000-97KWH-1H1 was identified as the most cost-effective and technically viable option for this demonstration; however, a switch was later made to the SOCOMEC SUNSYS HES L device to avoid direct competition as Huawei. The SUNSYS HES L offers greater storage capacity and a higher level of integration with other devices, enabling more efficient power flow management between the microgrid and the main grid. Additionally, SOCOMEC provides a dedicated device, the IM BOX, which autonomously manages ON-GRID and OFF-GRID modes. It includes an UPS (Un-interruptible Power Supply) that ensure power supply to control device even during ON-OFF grid transient. With a maximum capacity (nominal energy) of 196 kWh, a charging power up to 100 kW the SUNSYS HEL L has a charge/discharge rate of 0.5C and it's linked with inverters that can support and manage the off-grid PV+ESS system. The SUNSYS HEL L system features modular battery packs that can be easily added or removed from a dedicated fixed rack, offering a scalable energy solution for future needs. The rack's structure remains constant, allowing for seamless integration of additional battery modules as required. For ABB E-mobility's specific use case, the BESS will be equipped with a total of 4 lithium iron phosphate cells with a nominal capacity of 46,5 kWh each. In addition to that, the BESS is provided by SOCOMEC in a bundle together with further selected items to complete the configuration of an industrial microgrid. This device will be able to maintain the microgrid when it is disconnected from the grid, so it is designed to perform grid-forming functions; it will act as a voltage source and take care of frequency and voltage regulation of the grid, adjusting its values according to the output power. The BESS will generate the reference signals by itself, without using the reference values of the main grid, and will operate in isolated mode or in parallel with other grid-forming units. The network forming units can provide stability and inertia to the network and support it during faults or disturbances. A suggested implementation by SOCOMEC is summarized in Figure 25.

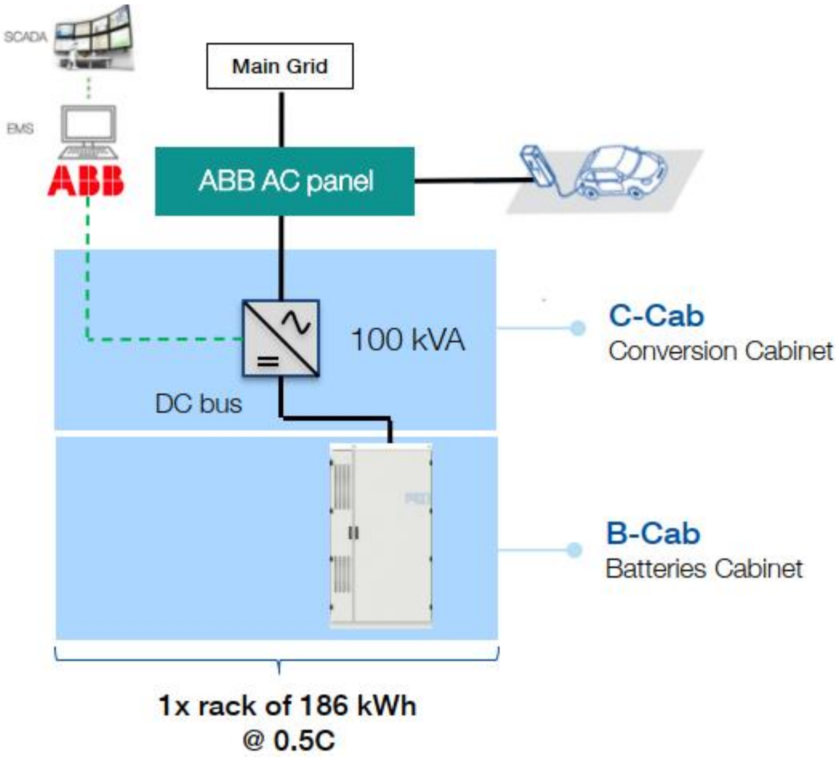


Figure 25. BESS system set up.

- **B-Cab - Battery Cabinet**:
  Energy Storage System (ESS): the ESS is composed by multiple cell array, placed on rack and stacked, and it's designed to store energy provided by Conversion Cabinet. The storage system is powered by "CATL" cells, a leading provider in the battery market, delivering optimal performance through LFP (Lithium Iron Phosphate) technology combined with advanced liquid cooling. Reliability and safety are further enhanced by SOCOMEC's state-of-the-art fire detection and suppression system.
  Capacity: 186/189 kWh / rack
  Outdoor Liquid-Cooled Battery Modules a Thermal Management: better performance and higher cooling efficiency
  Communication Architecture & BMS functions: Battery Management System optimized to recharge the battery pack minimizing cells aging
  Fire safety system: detection & cool down - included in each cabinet

- **C-Cab – Conversion Cabinet:** Smart Power Control System (PCS): The PCS is an inverter designed specifically to manage and optimize power flow within the Battery Energy Storage System (BESS). It regulates the charging and discharging processes across the array of cells, ensuring maximum efficiency and performance.

- **Master Controller, EMS and IMBOX**: The Microgrid Master Controller serves as the "brain" of the microgrid in “SOCOMEC” ’s proposed configuration. It coordinates and oversees the devices and operations within the microgrid to ensure optimal reliability and efficiency. By managing power flow, the MMC selects the appropriate electricity source, distributes power among loads based on the chosen strategy, and optimizes the utilization of the microgrid's various components. Acting as a power and energy management tool, it can, for example, regulate photovoltaic (PV) output under specific conditions or assist in the State of Charge (SOC) management of the Energy Storage System (ESS) during grid-forming operations. As part of the XL-Connect project, ABB E-mobility aims to develop an MMC capable of supporting bidirectional chargers and plans to test it on the Valdarno microgrid. In addition, our goal is to implement different charger strategies, based on users recharging behaviour, so the MMC will be able to exchange information with the chargers, BESS and check grid status as to set the total amount of power available that can be shared through all EVs connected.

All these elements together make the selected BESS capable of operating in microgrid mode, Figure 26, in particular:

- **Batteries Management:** ensure energy saving.
- **PV Management:** privilege self-consumption.
- **VE Smart Charging Operation:** implementing different charging strategies.
- I**slanding Management:** perform and verify all the step required to perform islanding mode
- **Pure Off-Grid functionalities:** power management according to limited amount of energy available

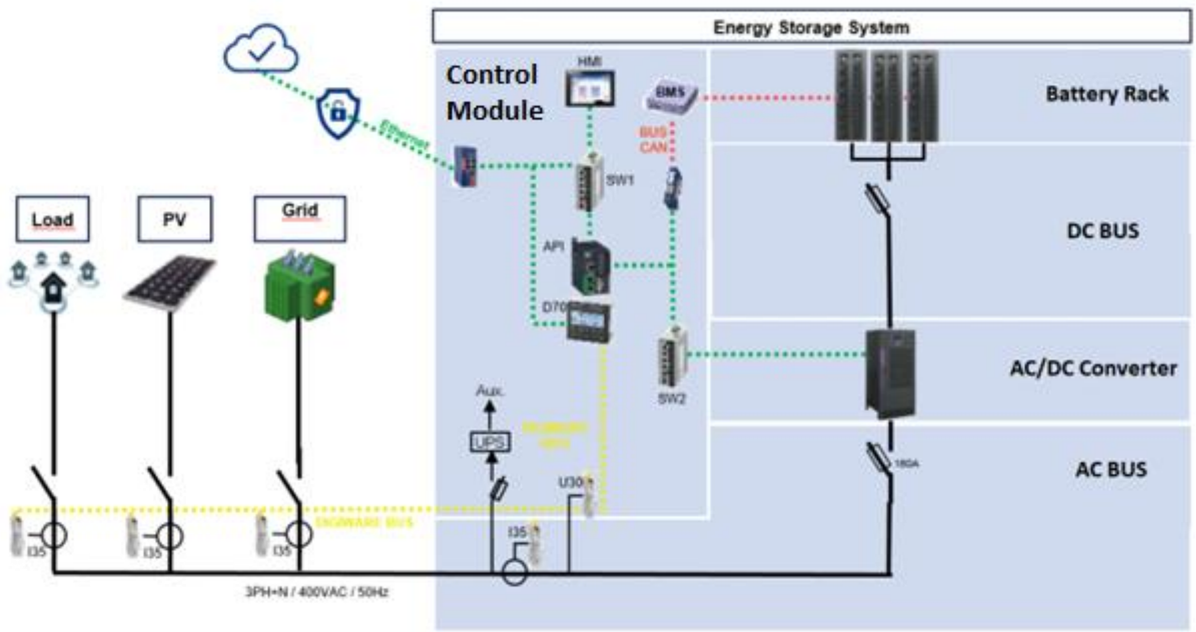


Figure 26. BESS features.

5.2 Data and Updates

The input data refers mainly to 3 elements: the photovoltaic system, the chargers, and the users; from the standpoint of the simulation, the data collected in the defined infrastructure can be divided into two main groups: the input and the output data. Before the physical construction of the microgrid, extensive data collection was conducted over one year span to capture real-world PV production patterns; additionally, plant consumption data was gathered to complement historical production records and also charging behaviour data of plant user’s. This data serves as a crucial input for simulating the microgrid's performance under various operating conditions and depend mostly on external factors like weather, number of employees, charger model, and more. The output data, on the other hand, are collected after the model has run, and are used to analyse its behaviour and functionalities. By incorporating this data, the simulation models more accurately represent real-world conditions the microgrid may encounter; this enhances planning and enables more effective optimization of energy management strategies. This data-driven approach ensures that the microgrid will be designed with a robust understanding of its potential operating conditions, contributing to a more reliable and effective implementation.

5.2.1 PV Data

Starting with the PV data, real data collected directly on the plant are used. The data used in the model refers to a typical 365-days period, from January to December, with a time granularity of 15 minutes between each measurement. The data are divided by season and by weekday, with the aim of creating an average PV production profile over a week (Monday to Sunday) for each of the four seasons, see Figure 27. Looking at the curves in the images below, they show the classic symmetric bell-shape, with the highest point being greater in the sunnier seasons (summer and spring) as one would expect. In general, the curves do not show a very smooth shape, and this may be given by the fact that Valdarno has a very variable weather: often - specially from October to March - the fog submerges the plant limiting the solar irradiation towards the panels, other times passing clouds reduce the solar production for many minutes - or even hours. During summer 2023, for instance, the month of June was characterized by high temperatures and high solar exposition periods punctuated by heavy rain, while in July was predominantly sunny with extremely high temperatures that can affect the PV efficiency. Moreover, the humidity level in this area is very high, with an average of 70 % on a yearly basis and daily peaks of 99 %.

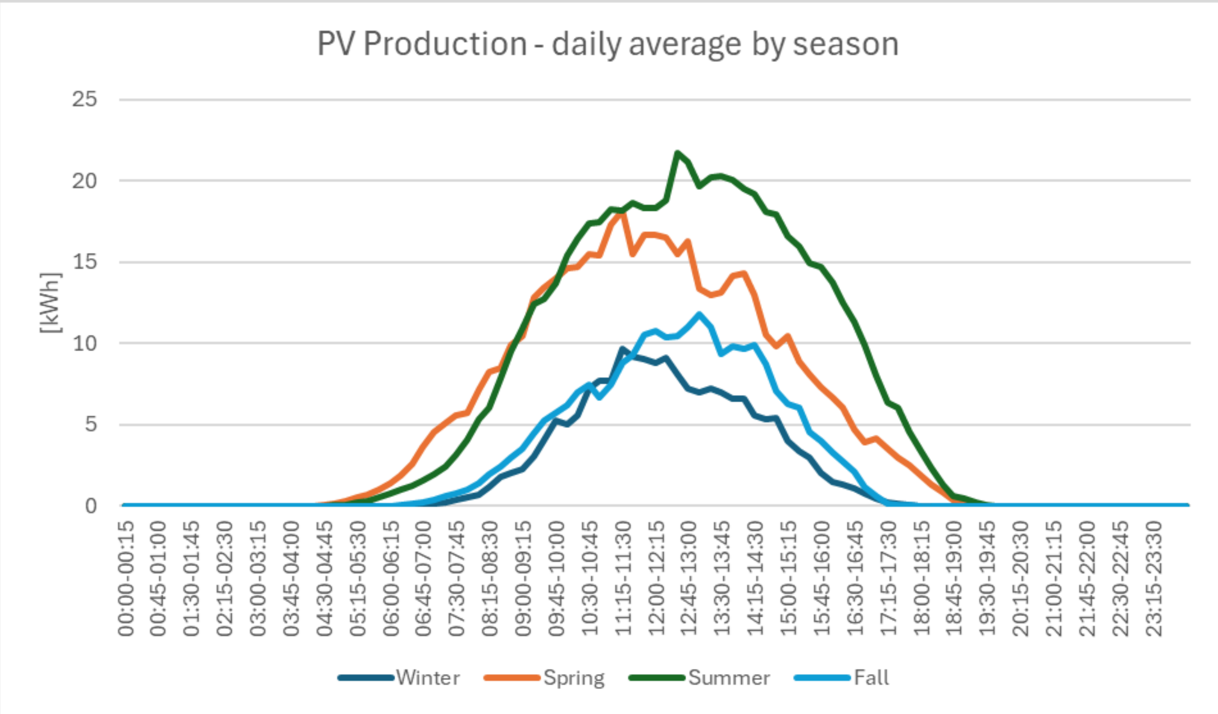


Figure 27. PV production, daily average.

To link the real-world demonstration to the virtual simulation the performance of Valdarno's microgrid will be simulated and analysed across four distinct scenarios, each representing a different season. This approach is necessary because the microgrid's primary energy source, the photovoltaic (PV) system, is highly influenced by seasonal variations and weather conditions. As a result, the energy dynamics and operational behaviour of all other components within the microgrid can vary significantly depending on PV output. To account for this variability, the PV dataset has been segmented by season and further categorized by weekdays. This segmentation enables the calculation of the average PV production for each 15-minute interval on every weekday within each season. The results of this analysis are illustrated in Figure 28.

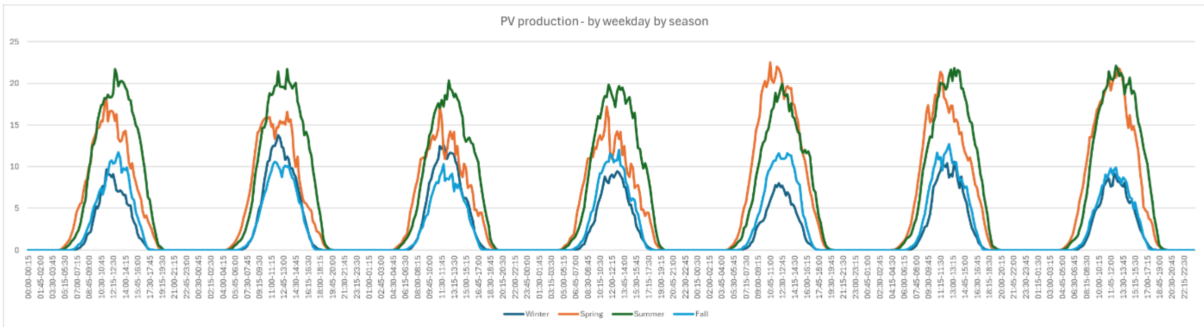
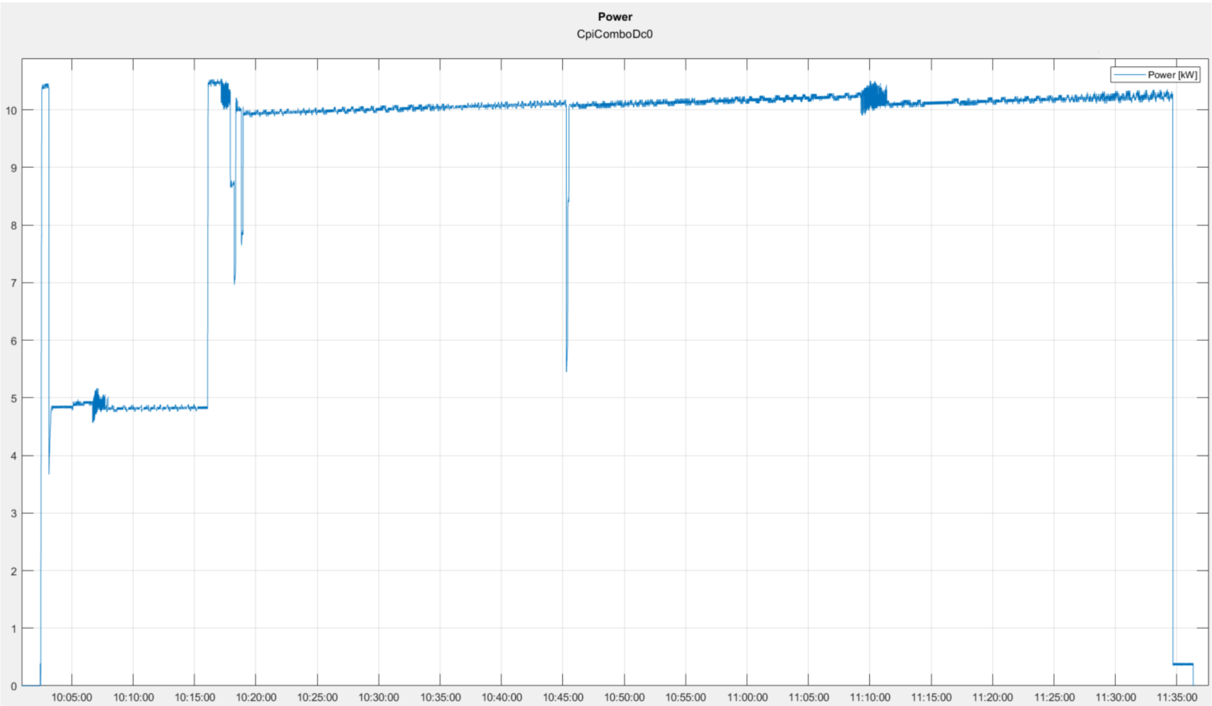


Figure 28. PV production, weekday by season.

5.2.2 Charging Data

A further input to the model is the charging data; they include both the behaviour of the charging stations as well as the of the users. On the charging stations side, two kinds of chargers operate in the microgrid: the AC Wall box and the DC bidirectional charger. When charging using an AC Wall box, the current is converted into DC – to then be delivered to the vehicle's battery – by the OBC (on board charger) located inside the vehicle. Analysing the market of electric vehicles, and more specifically the cars used by ABB E-mobility's employees, most of the OBC currently on the market provide a maximum nominal power of 11 kW. The Terra AC Wall box has a nominal maximum power of 22 kW, but considering the limitation of the OBC, in the model a charging curve with a peak of 11 kW is considered. Considering now the bidirectional DC charger, normally the charging curves of an AC and a DC charger differs a lot due to the much higher power that a DC power can delivered.



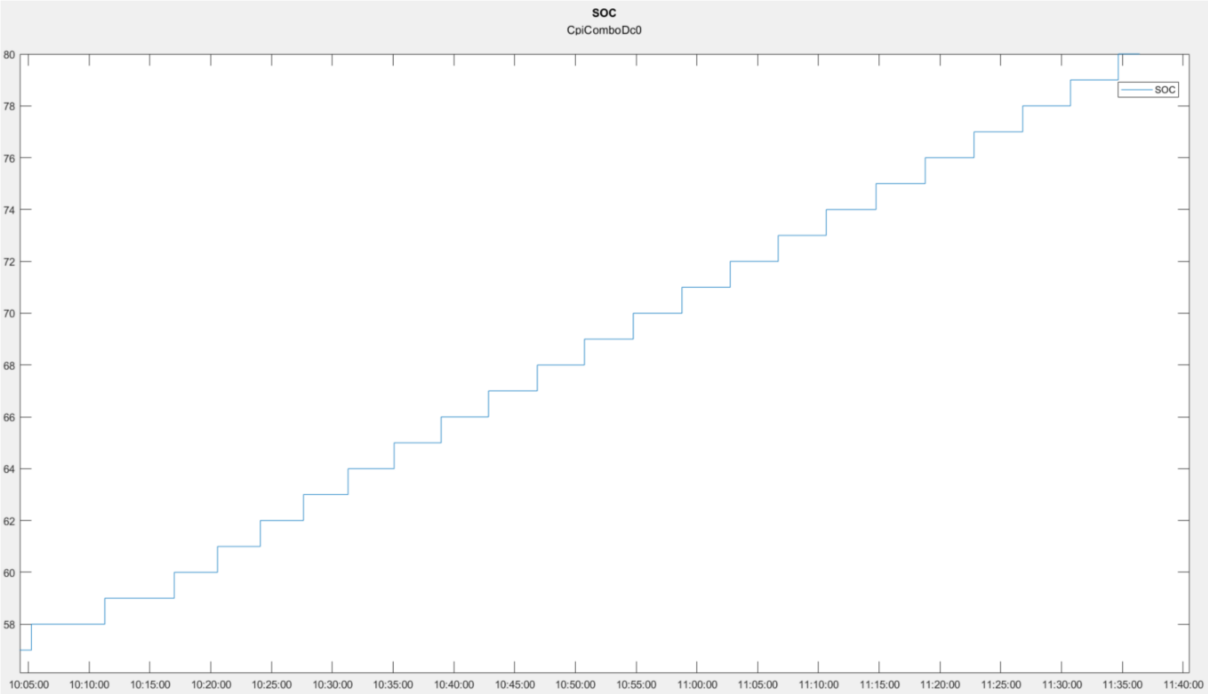


Figure 29. State of Charge and Power curve.

In Figure 29 is shown a real recharge profile performed with Terra Nova 11J, equipped with CCS connector, coming from ABB Belgium site; the same kind of charger will be installed in our demonstrator in San Giovanni. The data are collected into a dedicated ABB cloud, and it can be downloaded, in .txt format, ì processed and plotted via MATLAB as to have a better data resolution; the structure of load files is fixed, and the kind of EV is not available due to privacy policy. The recharge timespan is one hour, and thirty minutes and the SOC increase from 57% to 79%; the first spike is caused by cable check operation, then the power delivered is limit by EVs internal BMS at 4,8 kW. Then, after fifteen minutes of recharge, the power increase to 11kW reaching the maximum power output of the charger and maintaining it constant within end of the charging session.

On the other side, how often and for how long the chargers are used depends on the site-specific behaviour of the users and on what kind of EVs they own. Internal research on the user behaviour of ABB E-mobility's employees has been conducted: charging habits, vehicle types, and other factors have been observed over a time period of one year, and a "standard" week of data has been generated based on them. A generalization of the user behaviours can be briefly explained in the next section. The reason behind creating a standard week is related to the fact that ABB E-mobility Valdarno is a production plant, and therefore the behaviour of the employees is mostly affected by the working hours, while other factors – such as weather or convenience – are less impactful. The total demand of the chargers is the sum of the demand of 24 EVs, which have been individuated analysing the specific ABB E-mobility use case. 15 EVs belong to employees, 1 EV is used by the service team, while the company's fleet is composed of 6 EVs. In addition to that, the charging profile of 2 guests has been estimated based on last years' experience, when often guests came to the plant with an EV and charged their vehicles. For each user, an arriving time and a parking time have been assigned on each day of the week, as well as the distance covered by the employees to reach the plant and their home office habits have been included. The result of this analysis is shown in the figure below. This standard week has been used for the whole simulation, since, as mentioned above, it can be assumed that the users behave uniformly during the year.

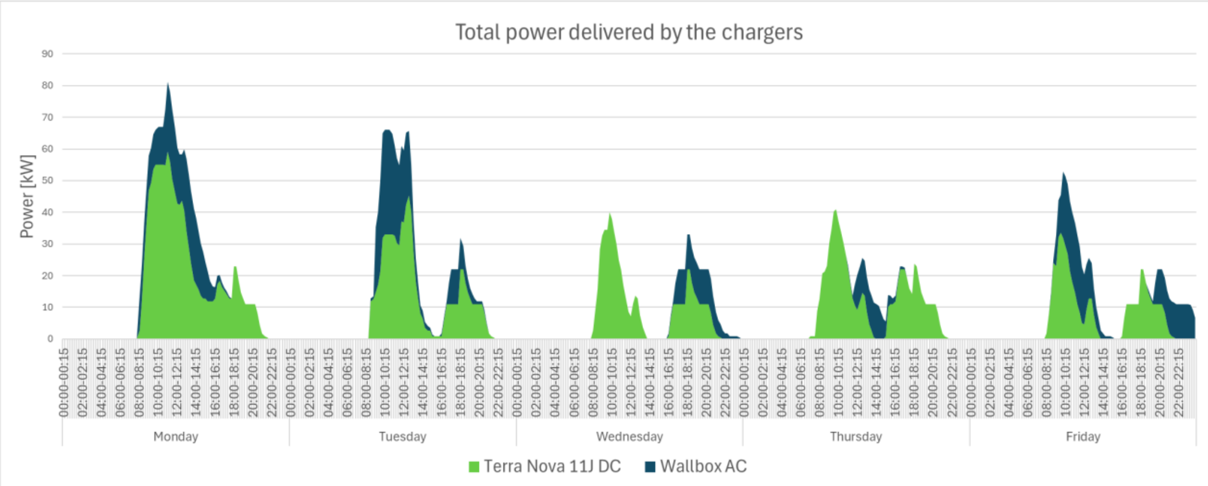


Figure 30. EV demand divided by type of charger delivering the power.

It can be observed that from Monday to Friday, the highest peak of demand is reached at the beginning of the shift (between 8 AM and 10 AM). This reflects the reality, as this is the time when the employees, who are the biggest share of EVs considered, arrive at the workplace and plug their car in. The second peak of the day, which is at the end of the working day at around 6 PM, is generated by the pool and service vehicles, which are used during the day for work-related activities and are then plugged in to be fully charged for the next day.

5.2.3 Users' Behaviour

In the previous sections, the general behaviour of the microgrid's users and components have been described, with a keen eye on the implementation of the model. However, how the users behave in general can be affected by aspects that can change based on the analysed scenario. The users can specify for how long they will be parked, what is their desired final state of charge, and whether they want to allow discharging activities. In addition to that, priority to the charging sessions can be assigned (highest power delivered, higher price paid). Table 4 shows the profiles individuated by ABB E-mobility based on the parameters mentioned before, and how these profiles can be assigned to real users of Valdarno's plant.

Table 4. User general behaviour.

User	Charging time	Desired final SOC	Priority	V1G/V2G	Valdarno
Unknown	Not specified	Not specified	Low	Not specified	Guest
Time-based user	Specified	f(time)	Medium	Specified	Employee Manager
Energy-based user	f(final SOC)	Specified	Medium	Specified	Manager External firm/visitor
V1G superuser	Specified	Specified	High	V1G	Employee Manager Special guest

It's important to notice that, except for the two guests, all users of the model are time-based users, as this is the most common user when dealing with a production facility.

5.2.4 Scenario Definition and Parameters

The first observations can be done even before running the model simply by overlapping PV and EVs data (cf. Figure 31) where PV data are coming from real measurement and EVs charging profile is coming from internal data collection of EV employees' charging sessions. In general, when the PV curve is above the EVs curve, the EVs demand is fully covered by the electricity produced using the photovoltaic system. In this case, due to prioritization of REN self-consumption, the other components will not feed electricity towards the vehicles and the EMS will decide if and how to dispatch the PV electricity surplus through all EVs connected based on charging priority. On the other side, when the PV production is lower than the EV demand, the EMS must find a way to satisfy the load respecting the boundaries set by the parameters in the different scenarios. In this case the energy flow prioritization assumes a critical role to both maximizing the satisfaction of the user and minimizing the total amount of energy drained from BESS.

Figure 31. PV production and EV demand comparison.

The presented model is a static model, in which some parameters are set, the simulation is run and then the output is presented and analysed. The parameters are set before starting the simulation and cannot be changed while the simulation runs. A dynamic model is expected to be created later during the project, once all the components of the microgrid are installed and more real data are available. Developing a static model is valuable for analysing how the microgrid performs under well-defined scenarios. It allows for an assessment of whether the system components are appropriately sized and provides initial insights into the overall project. This process supports the continuous improvement of the microgrid design by identifying potential issues early, thus avoiding costly errors during physical implementation. The parameters of the static model are presented in the Deliverable 5.2, and those highlighted in red are adjustable, with their allowable ranges specified. These can be modified as needed to align with the requirements of the specific scenario under study.

5.2.5 KPIs Definition

These parameters are very important to get an overview about microgrid performance and allow to compare and evaluate different sites because they're not related to the size (numbers of EV, total amount of power etc…) and can be scaled up.

The KPIs besides are referring to energy usage and users' satisfaction

- **EV Satisfaction:** allow to evaluate the quality of the scenarios and the user's satisfaction after charger experience. It is calculated as the total amount of electricity delivered to the EVs divided by the total EVs demand: Ideally, this KPI should be as close to 100% as possible, since an EV Satisfaction of 100% means that the microgrid is capable of satisfy the whole demand coming from the users.

$$\text{EV Satisfaction } = \frac{Energy\ delivered\ to\ EVs}{\text{EVs energy demand}}\ [\%]$$

- **Self Sufficiency and Grid Exchange:** further important aspect to quantify is to what extent the microgrid can rely on its own self-produced and stored electricity to fulfil the load's total demand. It is calculated using the total internally available electricity (thus excluding the main grid contribution) delivered to the loads, divided by the total electricity delivered to the loads. It represents the percentage of electricity used in the microgrid not coming from the main grid but only from the microgrid's components (PV, BESS, and V2G EVs). A self-sufficiency of 100% means that the microgrid is totally independent from the main grid. The XL Connect project requires ABB E-mobility and the partners to prove with their real-life implementation, as well as with their simulation, that the microgrid is able to reduce the electricity supply from the grid by at least 50%, in favour of onsite available electricity. This indicator is complementary to the self-sufficiency: a self-sufficiency of 60% means that the supply from the grid has been reduced by 60% (ergo Grid Exchange=-60%) compared to a case in which no microgrid is installed and the whole electricity is drawn from the grid

$$\text{Self sufficiency} = \frac{Energy\ delivered\ to\ loads\ from\ internal\ resources}{Total\ energy\ delivered\ to\ loads}\ [\%]$$

- **Decoupling Factor:** This KPI measures how effectively on-site electricity production is utilized within a microgrid, reflecting the quality of its energy management. This KPI emphasizes the synchronization of electricity generation and consumption, aiming for maximum alignment to enhance efficiency and reduce waste. In essence, electricity should ideally be produced and consumed simultaneously to ensure optimal satisfaction of demand while minimizing inefficiencies. The Decoupling Factor quantifies the extent to which undelivered electricity could have been used if production and consumption were better aligned.
    - A decoupling factor of 0 means that the whole demand is satisfied with the current configuration, but it does not give any additional information on whether this is due to a perfect coupling of production and consumption or just to an overall high level of production. This point can

be clarified combining it with the overall values of production and consumption: if they are similar, the system is well managed, otherwise is just the production that is so high that there is no need to manage it to fit the consumption.

- A decoupling factor between 0 and 1 means that potentially enough electricity is produced on-site throughout the week to completely satisfy the load’s demand, so an optimized management of the electricity could lead to a complete self-sufficiency and satisfaction of the microgrid.
- A decoupling factor above 1 means that even with an optimized use of the on-site produced electricity, the demand cannot be fully satisfied just using it, but a certain quantity of external electricity, when possible, is required. Nonetheless, the more the value is close to 1, the more the whole system would benefit from an optimized electricity management.

5.2.6 Scalability

In relation to our demonstration, the system is designed for scalability and replication to handle significantly higher power levels, ranging from over 200 kW to several megawatts. This would involve maintaining the current configuration while scaling up components, including the ESS (energy storage system) battery, increasing the number of V2G (vehicle-to-grid) chargers, and expanding the total installed PV (photovoltaic) power capacity. To achieve this, it will also be necessary to resize inverters and assess the feasibility of enhancing the MPPT (maximum power point tracking) configuration to optimize solar energy production, tailored to the size and location of the solar plant. The system could further serve as a platform for testing advanced charging logic by implementing various strategies. This includes prioritizing charging schedules based on revenue optimization, balancing trade-offs between battery aging and user profitability, and accounting for demand and resource availability. Additionally, the demonstration can be extended and integrated into different software platforms to simulate a variety of scenarios. These might include:

- Analysing user behaviour patterns.
- Testing transitions between island mode and grid-connected mode.
- Exploring the impacts of fluctuating ESS storage levels and varying solar irradiation.

Looking ahead, the primary objective of our project is to develop a virtual model of a DC microgrid, leveraging insights from the AC model results. This will enable us to demonstrate the scalability and flexibility of the system, paving the way for broader implementation.

5.3 Outlook and Risks

Related to Valdarno's demonstrator, below are listed some risks and mitigation measurements based on actual state of art for V2G, evaluating both EVs and charger perspective, taking in care about protocol standard compliance and availability of V2G EVs. The status and updates are shown also in Figure 32.

Risks

- Difficult to find compliant V2G EVs equipped with CCS due to EVs constructor delay to implement bidirectional technology.
- Protocol communication and grid certification for V2G in Italy.
- No compliance of EVs with ISO 15118-20.

Mitigation Measures

- Planning to use CHAdeMO EVs, already compliant with V2G, for first measurements and tests. Collecting additional data from:
    - Terra Nova 11J is equipped with CHAdeMO and simulator: V1G and V2G test and data.
    - Data from V1G charging session performed from Terra Nova 11J equipped with CCS and real EV.
- Not found; this issue affects all V2G projects in Italy due to DSO and TSO lack of standards.
- Using simulator, but real data are not collectable due to EV unavailability.

Figure 32. Current status and updates.

6 ABEE Demonstration

6.1 System Setup

The system is comprised of a sector-coupled unit situated at the ABEE headquarter in Ninove, Belgium. Depending on application scenarios, it can function either as an "individual remote self-consumer of renewable energy" or as a "remote active customer utilizing the distribution network.". The diagram is shown in Figure 33.

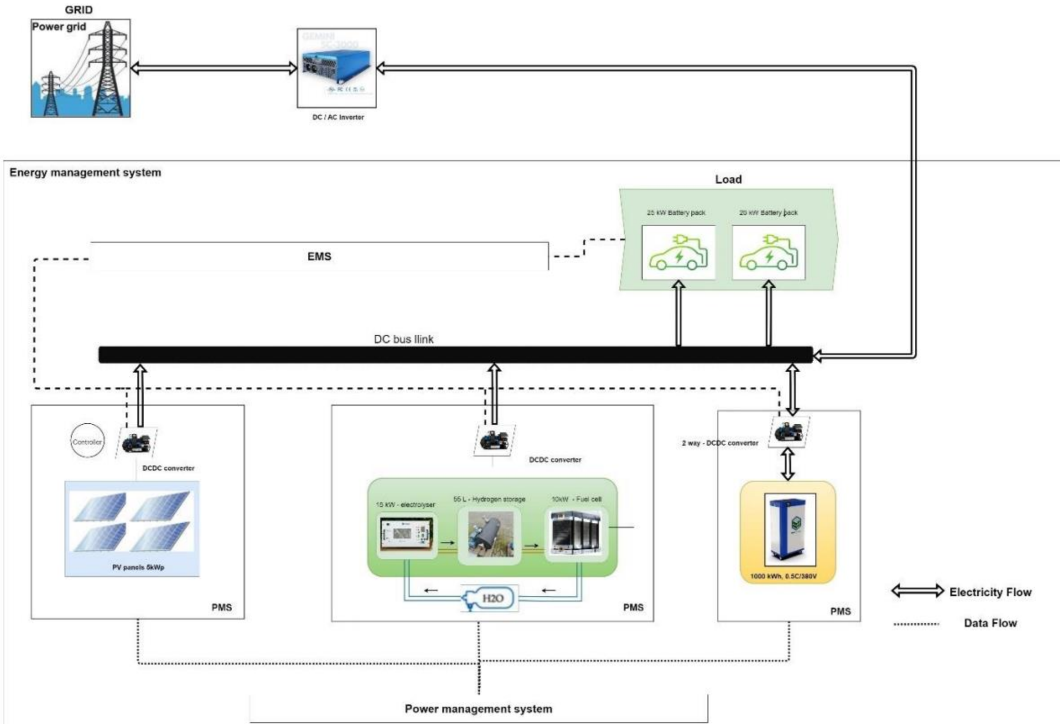


Figure 33. ABEE demonstration diagram.

Key specifications include:

- Limited access to the unit at ABEE headquarters, restricted to ABEE employees.
- A hybrid converter exchanges the power between the public grid and local micro grid.
- A bidirectional EV emulator equipped with a DC charging point with a power load of 10 kW.
- Charging is facilitated through a hydrogen and photovoltaic system, featuring an expected nominal power output of approximately 10 kW.
- Storage system utilizing batteries with a capacity ranging from 5 to 10 kWh and a hydrogen & fuel system cell with a capacity of 5 kW.

- A 5 kWp PV system.
- Control system enabling communication, monitoring, and remote control via EMS (Energy Management System) and PMS (Power Management System).

Depending on the availability of power from the photovoltaic system, solar energy is utilized to produce hydrogen through an electrolyzer. The generated hydrogen is then stored in a 55 litre tank in compressed form. The storage duration for hydrogen can vary from days to weeks, depending on power demand. Simultaneously, hydrogen fuel cells are employed to generate electricity using the stored hydrogen, which is subsequently stored in battery packs, or supply the load. The stored energy in the battery packs is used for charging electric vehicles (EVs), when needed. This entire process is bidirectional, allowing energy flow from the grid to the EV/battery storage system and vice versa (Vehicle-to-Grid, V2G). Solar panels, hydrogen fuel cells, or the power grid can supply energy or electricity under different conditions.

The demonstration is carried out via the following steps:

- Procurement process for acquiring equipment, including obtaining and reviewing quotations before finalization.
- Conduct a separate dry run of the equipment, if feasible.
- Integrate the equipment into the local DC grid and initiate operation without optimization. Exercise caution regarding power fluctuations and conduct testing for safety protection and communication systems.
- Set up XL-connection algorithms and controllers, ensuring a thorough understanding of the algorithms.
- Integrate XL-connection algorithms and controllers, subjecting them to intensive testing under various scenarios for a demonstration.

The status is presented in the Figure 34.

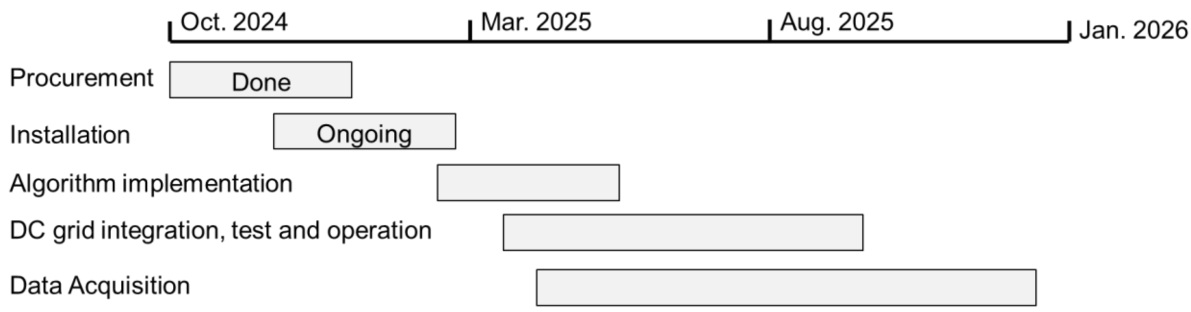


Figure 34. ABEE status Gantt.

6.1.1. Data and Updates

Currently, ABEE assembles and installs the equipment step by step. First, the battery is assembled in the ABEE factory (cf. Figure 35).

Figure 35. BESS used in ABEE demonstrator.

This battery is composed of 16 LFP cells. The nominal voltage is 51 V. The standard charging/discharging current is 140 A. The BMS is responsible to monitor the cell/pack voltages, current and temperatures. It is also equipped with overcharging, over-discharging, and over temperature protections. The cells are balanced in the way of passive balancing. The max balancing current can reach 200 mA. Currently, the PV system in ABEE site is connected to local AC microgrid. To create a PV input to the proposed DC microgrid of XL-Connect, a PV emulator is done in a cost-effective way which utilizes a Delta power supply, SM210-CP-150. Please see the Figure 36.

Figure 36. PV emulator.

This power supply can be programmed easily via the front UI, web interface, or Ethernet in order to emulate the PV voltage, current or power. The outputs can reach 210 V DC, 150 A or 15 KW. Moreover, it can recover the output voltage in just 200 µs after a load change from full positive current to full negative current and vice versa. This dynamic response is adequate to simulate dynamics of PV outputs. As one important part of DC microgrids, a hydrogen system, including electrolyzer, tank and fuel cell was purchased. It will be used to coordinate PV, EV, storage and grid, to maximize PV production and minimize the grid power intake. The hydrogen production depends on the need of balancing PV generation and demand, following operation conditions. The tank is a buffer for hydrogen production. When needed, the hydrogen is converted into electricity via fuel cell and injected back to DC micro grid. The prototype of hydrogen electrolyzer is shown in Figure 37.

Figure 37. Hydrogen electrolyzer prototype.

It can produce 0.6 Nm3/h with a purity of 99.999 %, which satisfies the requirement of fuel cell. Considering the application of DC microgrid, the power input of electrolyzer is revised into 350 V DC. It can be started remotely by Modbus, after configuring properly the hardware. A 5 kW hydrogen fuel cell is on the way. Its output can be controlled by CAN communication.

The DC bus voltage is set at 350 V. So, the battery, EV emulator, PV emulator must be connected via a DC/DC converter. The DC/DC converter, shown in Figure 38, will arrive in January.

Figure 38. DC/DC converter.

This is a 5 kW, bi-directional DC/DC converter, which supports parallel expansion. The low voltage input varies from 30 to 100 V DC. The high voltage output can reach up to 420 V DC.

6.2 Outlook and Risks

Following the arrival of selected equipment, the presented demo above is being implemented step by step. So, the battery, PV emulator and hybrid converters are tested. The first platform without hydrogen system and fuel cell is shown as Figure 39.

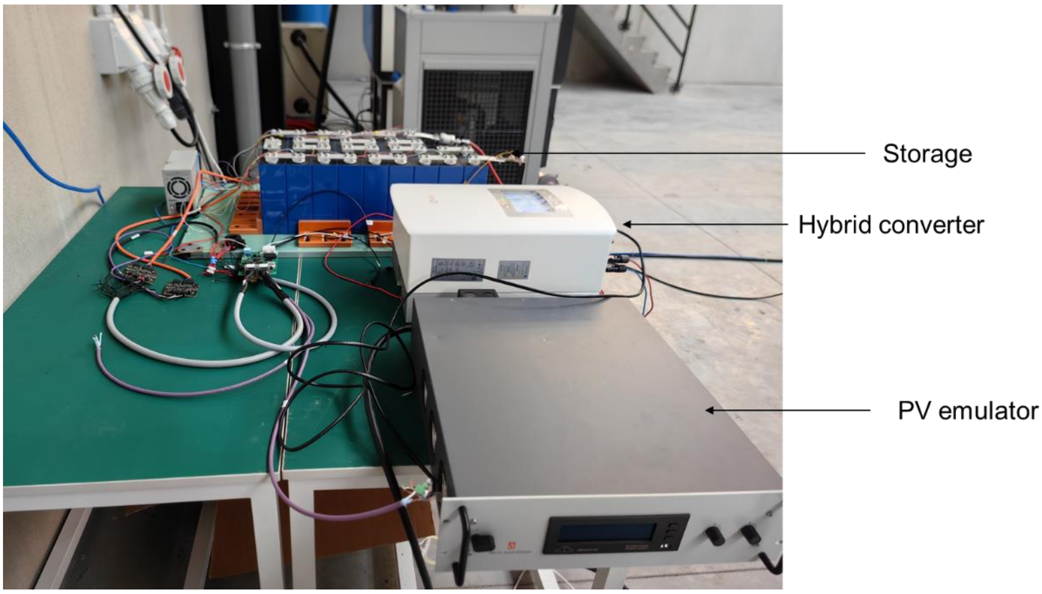


Figure 39. First platform without hydrogen system and fuel cell.

In this platform, Delta power supply plays the role of PV emulator. The battery storage works in a bi-directional way. The next step will incorporate more batteries (EV emulator), electrolyser and fuel cell. The XL-Connect algorithms will be tested in this demo. The first risk would be the interoperability of different devices, especially from the communication point of view. The electrolyzer manufacture adopts MODBUS. However, most of other equipment uses CAN communication or RS485. As a mitigation measure, a msg hub or translation center will be developed to translate MODBUS and CAN msg each other.

Other risk is how to regulate electrolyzer consumption automatically. Manually adjusting the electricity consumed by electrolyzer via knobs and valves still is not considered. The manufacture agrees to provide us one step-wise regulation via MODBUS msg, namely turn on/off. This is not a kind of smooth regulation. If setting points given by XL-Connect are continuous values. A solution will be to discretize them properly. A possible risk is the output duration which full cell can support, due to the size limit of hydrogen storage tank. One possible solution is to properly create/arrange demo scenarios to avoid running out of hydrogen.

7 Porto, Coimbra and Setúbal Demonstrations

The Portuguese pilot of the XL-Connect project, to be implemented at the E-REDES facilities in Coimbra, aims to demonstrate the viability and benefits of advanced charging solutions for Electric Vehicles (EVs) in a real-world context, focusing on the interoperability between the electrical grid and the charging platforms. The XL-Connect project, funded by the Horizon Europe program, has the primary objective of optimizing the entire EV charging chain, from energy supply to the end user. It represents a unique opportunity to test and validate advanced EV charging solutions in a real-world context. E-REDES' active participation will allow optimizing the integration of electric mobility into the distribution network, contributing to the creation of a sustainable and efficient electric mobility ecosystem in Portugal. Disseminating the pilot's results, both nationally and internationally, will be crucial to promote the replication of the tested solutions and accelerate the transition to large-scale electric mobility. The choice of Coimbra and the E-REDES facilities for this pilot is of great strategic importance. E-REDES, as the operator of the electricity distribution network in Portugal, plays a crucial role in integrating electric mobility into the national energy system. E-REDES' participation in the XL-Connect project will allow:

- Evaluating the impacts of EV charging on the local electrical grid, monitoring aspects such as energy quality, voltage fluctuations, and the occurrence of overloads.
- Optimizing the integration of advanced charging solutions, such as “EaVy” Charging, into the distribution network, contributing to the stability and reliability of the electrical system.
- Developing and implementing smart charging strategies that maximize the use of renewable energy and minimize operational costs.
- Testing the interoperability between different charging platforms and the electrical grid, ensuring compatibility and efficient communication among the various stakeholders in the electric mobility ecosystem.

7.1 System Setup

The XL-Connect project will explore various advanced charging solutions with the objective of optimizing the use of charging infrastructure and minimizing the impact on the electrical grid. Among the technologies to be tested in the Portuguese pilot, the following stand out (cf. Figure 40):

- **EaVy Charging:** An innovative sequential charging system that allows managing the charging of up to 10 EVs using a single 50 kW fast charger. This solution, described in the document "EaVy Charging Universidade EDP.pdf," presents significant advantages in terms of efficiency, flexibility, and reduction of infrastructure investment.
- **Smart Charging (V1G/V2G/V2X):** The project will investigate and test different modes of smart charging (real), including Vehicle-to-Grid (V2G) (simulation) and Vehicle-to-Everything (V2X) (simulation). The objective is to evaluate the potential of these technologies to provide flexibility services to the electrical grid, such as energy storage and demand control.
- **Advanced Communication:** The project will develop and test a generic communication structure based on open standards, aiming to ensure interoperability between the different components of the charging system, including EVs, charging stations, management platforms, and the electrical grid.

Figure 40. E-REDES Demonstrator main actions.

The implementation of the Portuguese pilot at the E-REDES facilities in Coimbra (cf. Figure 41) requires the installation of the necessary infrastructure to support the advanced charging solutions, including:

- Dedicated EV charging parking spots equipped with the technologies to be tested.
- Fast charger compatible with smart charging solutions and advanced communication structures.
- A prototype centralized management and control system to monitor and manage the operation of the charging solutions and their interaction with the electrical grid.

- Connection to the electrical grid with sufficient capacity to support the additional load of the chargers and ensure the reliability of energy supply.

Figure 41. Implementation in the Coimbra facility.

The selection of participants in the pilot should consider the diversity of usage profiles and charging needs, with the objective of covering different scenarios and collecting representative data. Among the potential participants, the following are highlighted:

- E-REDES employees who use EVs.
- E-REDES customers who reside or work in the Coimbra area and use EVs.
- Invited users, selected through an application process, to cover specific usage profiles and charging needs.

7.2 Data and Updates

Monitoring and evaluating the Portuguese pilot of the XL-Connect project will be crucial to determine the technical and economic viability of the advanced charging solutions, as well as their impact on the electrical grid and user experience. The main indicators to be monitored include:

Technical:

- Charger usage rate: The percentage of time the chargers are in use.
- Average waiting time to start charging: An indicator of the convenience and efficiency of the charging management system.
- Performance of smart charging solutions: Evaluation of the capacity of smart charging technologies to provide flexibility services to the electrical grid and contribute to the integration of renewable energies.

- Interoperability between charging platforms and the electrical grid: Analysis of the compatibility and communication between the different components of the charging system.
- Impact on the distribution network: Monitoring of energy quality, voltage fluctuations, and the occurrence of overloads.

Economic:

- Operational costs of charging solutions: Analysis of energy consumption, system maintenance, and other relevant factors.
- Return on investment in charging infrastructure: Comparison of the implementation and operational costs of advanced charging solutions with the benefits obtained in terms of efficiency, flexibility, and reduced impact on the electrical grid.

Social:

- User satisfaction level: Evaluation of the ease of use, reliability, and convenience of the charging solutions.
- Impact on the adoption of electric mobility: Analysis of the pilot's contribution to promoting the use of EVs in Portugal.

Environmental:

- CO_2 emission reduction: Estimation of the reduction in greenhouse gas emissions resulting from the use of EVs compared to combustion vehicles.

Disseminating the results of the Portuguese pilot of the XL-Connect project will be essential to share the lessons learned and promote the replication of advanced charging solutions in Portugal and Europe. The dissemination activities, coordinated by E-REDES, will include:

- Preparing and publishing detailed technical reports on the pilot implementation, results, and project conclusions.
- Participating in conferences, workshops, and relevant events in the energy and electric mobility sectors.
- Publishing scientific articles in reference journals.
- Disseminating results through press releases, social media posts, and other media channels.
- Organizing workshops and demonstration sessions to present the tested solutions to potential users, partners, and other stakeholders.

7.3 Outlook and Risks

The implementation of the Portuguese pilot of the XL-Connect project involves several potential risks that require careful identification and mitigation. The demonstrator is expected to be fully operational in 2025, with the coming months dedicated to the setup of the necessary infrastructure, systems, and processes. The risks and the mitigation actions are described below.

Risks:

1. Delays in infrastructure installation and setup of interoperability.
2. Technical Challenges. Compatibility issues between charging platforms and the electrical grid
    a. V2G standard not defined in the demonstrations active plan
    b. No V2G EVs available for V2G with CCS port.
3. Insufficient Participant Diversity. Limited variety in user profiles could reduce the representativeness of the pilot data.
4. User Resistance; resistance to new technologies or dissatisfaction with system usability and reliability.

Mitigation Actions:

1. Establish close coordination with suppliers, contractors, and technical teams to ensure timely delivery and installation. Also, will be performed a pre-installation testing and validation of interoperability features to identify and resolve issues early.
2. Utilize alternative methods such as simulated V2G scenarios to assess potential benefits and challenges.
3. Design a structured participant selection process that targets diverse user profiles.
4. Provide intuitive and user-friendly interfaces to enhance ease of use.

8 Real Demonstration Actions: Management

8.1 Data Management and Relation to Task 5.4

In alignment with Task 5.4, the data collection process across the five demonstrators is designed to ensure continuous monitoring and assessment of high-quality data during the demonstration phase (cf. Figure 42). This process guarantees that data is comprehensive and suitable to serve as inputs for subcomponent modelling in Task 4.2 and for the optimization of control strategies in Task 4.3.

For all demonstration sites, data is initially collected on-site using dedicated devices capable of local storage and immediate processing for on-site operations such as energy management. This ensures reliable access to real-time data for operational needs. To centralize and standardize data handling, the collected data will be then transferred to a shared database using the MQTT protocol, which offers a robust and ISO-compliant framework for machine-to-machine communication. The centralized database, managed by FEV, provides a secure environment for storing and accessing data from all demonstrators. The structure of the database topics has been designed to be universal and adaptable. For example, as already discussed in chapter 3.3.2, the database set up was initially tested in Aachen demonstrator, serves as a template for the other sites. This small-scale example demonstrated the database's capabilities for data handling and visualization.

By November 2024, a comprehensive manual outlining the procedures for publishing data to the database was shared with all project partners. This documentation also provides guidance on how data can be manually or automatically extracted from the database for use in simulations or further analyses, a feature that is crucial for scalability testing and digital twin simulations. This choice, together with the adoption of cloud computing resources and the use of MQTT protocol, ensures that potentially all partners involved in real-world demonstration can implement the protocol in their activities, either using dedicated devices and gateways (e.g. Raspberry P boards) or on their main control systems.

It is worth noting that if the project receives an extension, Task 5.4 would be extended accordingly, allowing the collection and analysis of demonstration data to continue into 2025. This extension would provide additional opportunities to refine the data management process and extract more comprehensive insights from the demonstrators. The extended timeline would also ensure sufficient data from late-activated demonstrators, such as those at the UNIFI, ABB, ABEE, and E-REDES, further enhancing the overall project outcomes.

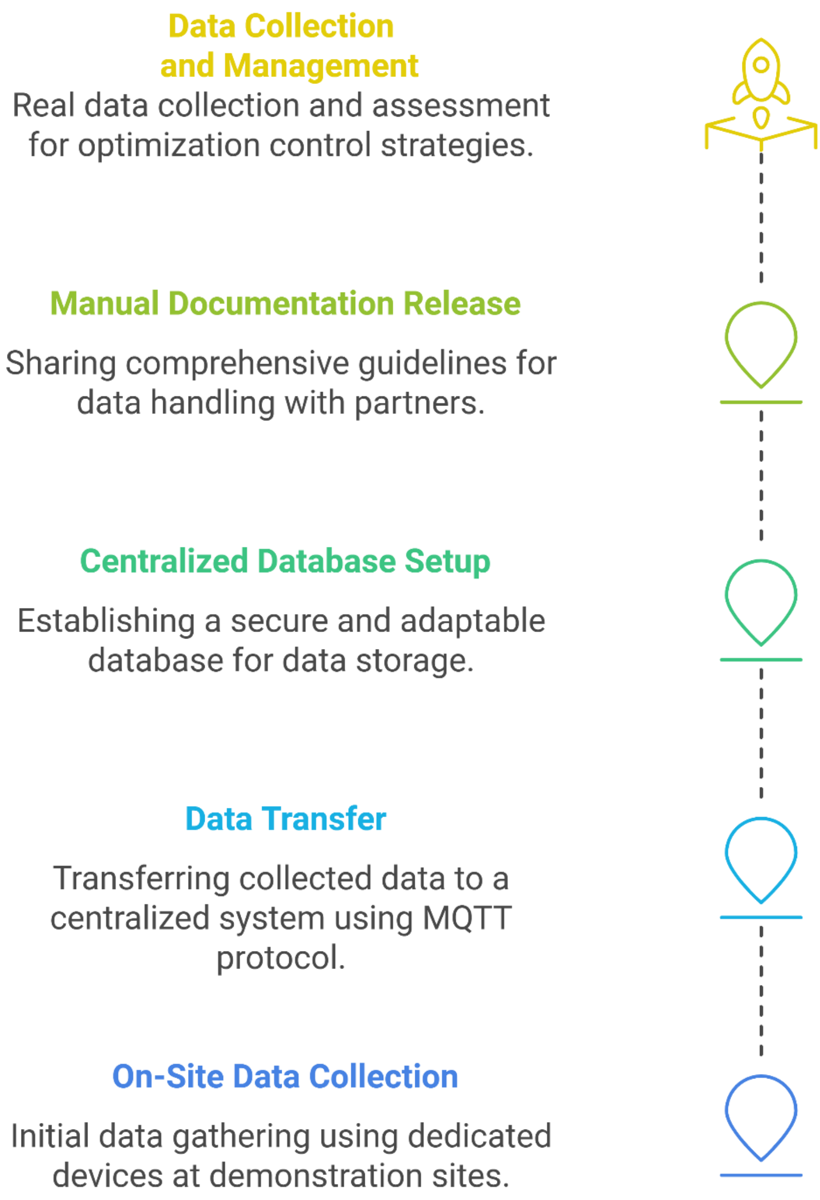


Figure 42. Data management and relation to Task 5.4.

8.2 Summary of Risks and Preventative Measures

Due to its nature, the XL-Connect project since the beginning dealt with the need to improve the Technology Readiness Level of charging systems providing V1G and V2G solutions. A large number of barriers, as described in former XL-Connect activities, were noticed and most of them are, in effect, providing their effect, as seen in the dedicated sections of each demonstration description. Amongst these, researchers can highlight a few frequent risks which are transversal to all actions:

(1) The limited availability of V2G-enabled vehicles and EVSE in the form of commercial elements: this is potentially hindering the real-world application in customer-ready solutions

(2) The difficulties for single users to access to the energy market for a number of reasons, including the existing regulation, the existing contracts and privacy reasons

(3) The need to integrate the innovative charging solutions V1G and V2G with other initiatives related to energy management, in order to optimize energy grid exchange, potentially reducing by 50% energy exchange through the grid borders.

A risk-table comprehending the point of view of all XL-Connect partners, not only those included in the real-world demonstration, has been created and updated periodically. However, in this paragraph a few notes regarding the solutions specific for real world demonstration are highlighted.

For risk number 1:

- The limited availability of EVSE stations has been acting on the partners stimulating the proposal of new components, which are under preparation by ABB and Circontrol partners, and will be available at least as laboratory equipment.
- The limited presence of V2G-enable cars on the market can hinder demonstration because the presence on the free-floating fleet is almost negligible, so that these type of charging events have to be observed and stimulated in controlled environment. Three interventions have been done on that:
    - For the Aachen case study, the integration between partners provided the availability of V2G vehicles, so that V2G tests will start as soon as the EVSE will be available
    - For the project in general, the topic has been discussed together with sister projects, in the “V2X Cluster Meeting” held on September 2024, highlighting the need to explore the availability at research and commercial level on a broad network. In preparation of this event, a call for contacts has been diffused in the XL-Connect consortium, in order to identify suitable partners which can potentially facilitate the access to V2X ready vehicles. On December 2024, the table includes 19 new contacts and discussions ongoing. Partners contacted include:
        - Manufacturers: Stellantis Group, MG Cars, Kia Group, Nissan Group, Honda Group, Mazda Group, NIO Group, Volvo group, VW Group.
        - EVSE Managers: CUBOS, DREEV, Atlante.Energy.
        - Vehicle Diagnostics: TEXA spa.

- The emulation of V2G energy exchange with additional equipment, such as:
  - Vehicle emulators (ABB), with bidirectional capabilities.
  - BESS (UNIFI).
  - Sector Coupling with energy exchange capabilities (ABEE) through H_2 conversion.

For risk number 2:

- At the first sight, the risk is not affecting those demonstration actions where the focus is on the technical point of view and the occurrence of the energy management is provided in a private context, such as:
  - The Regionetz drivers panel, for Aachen case study.
  - The University users panel, in the private laboratory.
  - The ABB users, in the private parking lot.
  - The ABEE users, in the private parking lot.
  - The E-REDES users, where the focus is on communication capabilities and data exchange.
- A potential foreseen risk is that user acceptance is not explored in detail due to the limited application on commercial services. For this reason, a continuous discussion within XL-Connect consortium is ongoing (through a 2-weeks meeting held regularly since project beginning) in order to stimulate commercial adoption of energy management strategies by those partners related to energy distribution or reselling. At the moment, such studies will be provided only after the successful implementation of technical innovation.

For risk number 3:

- XL-Connect consortium is communicating with electric grid experts in the Advisory Board in order to obtain regular feedback on the initiatives held. Currently, recent discussion highlighted that:
  - The energy exchange reduction priority is still valid, and all the demonstration actions can contribute to the shared objective to enhance interconnected system development in order to provide effective energy management on the sites involved
  - 50% reduction in grid exchange is a demanding target, which can be achieved through the introduction of multiple technologies, including V2G vehicles but also local energy storages

- A priority for the future will be probably on the provision of other kind of Grid services, such as short-time reactions in order to support grid stability. In this case, the focus is not only on system deployment (which is provided by demonstration case studies) but also on low-level design of converters and power meters, in order to be able to provide “grid forming services”. Such services are not part of the original XL-Connect priority, and their implementation on the new components designed for XL-Connect needs is currently not planned as a priority.

As a conclusion, the XL-Connect ambition is facing a number of risks, most of them were identified since the early preparation of the proposal and corrective actions have been identified and applied even before the materialisation of the risks. Certain unforeseen risks (Table 5) have been further identified and most of them can be related to the real-world demonstration actions. However, corrective measures – which are based on technological solutions (such as emulation adoption) and on broad network consultation – are under application at the current moment.

Table 5. Unforeseen risk table.

Unforeseen Risks	**Which months of the project are affected? (MX)**	**Did your risk materialise?**	**Did you apply risk mitigation measures?**	**Comments (if any)**
Information on critical infrastructure (i.e. power grid) and user power data (e.g. GDPR) strictly confidential, thus grid topology and power injections are not available.	Period 1	Yes	Yes	Generative grid planning procedures will be applied to create physical-based models. Anonymous typical cluster power profiles will be used for generation of power usage patterns. The methodology has been designed strictly modular without strict data source dependency. For example, data interfaces among computational modules are open and transparent, where novel data sources can be easily integrated.
Most OEMs will not deliver an official EV with ISO15118-20 before Q2-Q3 2025.	Period 1 Period 2	Yes	Yes	Possible project extension to ensure that V2G can be tested with ISO15118-20, or usage of emulators instead of real vehicles (see also foreseen risk #12).
Due to ongoing reorganisation processes at PARTNER processes are delayed.	Period 2	Yes	Yes	Regular meetings and follow-ups to monitor the status (Deliverable D3.3 and demonstration actions) and to find ways how to mitigate the effects of the delays (e.g. project extension).
Relevant information from other projects is not public/available (WP3, T3.2 and WP5, T5.3)	M12-M36	WP3, T3.2: Yes WP5, T5.3: Yes	WP3, T3.2: No WP5, T5.3: No	WP3, T3.2: The start of the subcontracting process for the UMEI developments was planned for April. The UMEI has been developed within another project involving partners external to XL-Connect and E-REDES had to align property rights with them before implementing any further developments to the UMEI. The process has suffered delays and currently there are still signatures missing. WP5, T5.3: The Portuguese demonstration is dependent on the UMEI developments.

Potential handover/change in task leader personnel	M25-M37	No	-	WP6

9 Concluding Remarks

The XL-Connect demonstration actions include both virtual and real-world activities, this latter being based on the application of the concepts defined during all project WPs in a working system.

The current status of the real-world demonstration includes the confirmation of the targets, the methods, the plans defined during Task 5.1, the early design phase, and also can now include the experiences provided by the know-how developed about system modelling (WP4) and virtual case studies (Task 5.2).

As a consequence, even if 5 different real world demonstrations actions are provided, a few transversals, shared objectives have been identified:

- Pushing for the transformation from “charging stations” to “smart charging systems and networks”, where different energy users and sources are coordinated to achieve power management targets, assuming that the large diffusion of V1G and V2G technologies will facilitate the conversion to smart networks
- Pushing for improved telecommunications through flexible, interoperable ICT solutions, finding out aggregation systems and data exchange systems which can adapted to different technologies and concepts
- Focus on the “system” architecture rather than on the single technology, providing the required grid services through V1G and V2G applications but keeping on mind that such a broad number of technologies can contribute to the same objective. BESS, emulators, energy sources should be identified on the basis of the service they can provide rather than on their constituting elements.

The later point of this approach is the key factor to proceed with real-world demonstrations mitigating the risk that the inertia of the market in introducing EVSE, Vehicles, and business solutions would hinder system creation.

Most recent information on demonstration sites highlights that:

- Software solutions for energy management have been prepared and are ready for prototype implementation.
- Hardware solutions are still under development or under acquisition, and most of the installation will take place during the early months of 2025.

- Real-world data, when available (e.g. Aachen, Florence and San Giovanni demonstration sites) have been used to correct system sizing and to confirm or recalibrate the original assumptions.

Outlook for the second XL-Connect period is the confirmation of the solution installation and the achievement of a stable operative life, which will provide the data needed for objective achievement status, for system calibration and, finally, for environmental and economic assessment of the impact of the newly introduced technology. Real world data will therefore exploit two main scopes:

- A per-se scope, that is to demonstrate the applicability of certain solutions in the considered context
- A to-be scope, that is to provide the validated data for further system scale up, through virtual methods and through broader demonstration actions in the future.