V2G product/software

Project deliverable D2.4

This project has received funding from the European Union's Horizon Europe research and innovation programme under grant agreement No 101056874.

WWW.SCALE-HORIZON.EU

1 Deliverable administrative information

Deliverable number	D2.4
Deliverable title	V2G product/software
Dissemination level	Public
Submission deadline	31/01/2025
Version number	Final 1.0
Authors	Kevin Haesevoets
Internal reviewers	ABB, WDS, Hyundai, Trialog, Elaad, Renault
Document approval	Baerte de Brey (ElaadNL)

Legal Disclaimer

SCALE is funded by the European Union’s Horizon Europe Research and Innovation program under Grant Agreement No 101056874.

Social Links:

twitter.com/scaleproject_

www.linkedin.com/company/ scale-project-smart-charging-alignment-for-europe

www.youtube.com/channel/UC1HVFu5uJPCNSV96b3l_rcg

For further information please visit WWW.SCALE-HORIZON.EU

SCALE introduction

SCALE (Smart Charging Alignment for Europe) is a three-year Horizon Europe project that explores and tests smart charging solutions for electric vehicles. It aims to advance smart charging and Vehicle-2-Grid (V2G) ecosystems to shape a new energy system wherein the flexibility of EV batteries' is harnessed.

The project will test and validate a variety of smart charging and V2X solutions and services in 13 use cases in real-life demonstrations in 7 European contexts: Oslo (NO), Rotterdam/Utrecht (NL), Eindhoven (NL), Toulouse (FR), Greater Munich Area (GER), Budapest/Debrecen (HU) and Gothenburg (SE). Going further, project results, best practices, and lessons learned will be shared across EU cities, regions, and relevant e-mobility stakeholders. SCALE aims to create a system blueprint for user-centric smart charging and V2X for European cities and regions.

SCALE's consortium comprises 29 cutting-edge European e-mobility actors covering the entire smart charging and V2X value chain (equipment and charging manufacturers, flexibility service providers, research and knowledge partners, public authorities, consumer associations, etc.) It is led by ElaadNL, one of the world's leading knowledge and innovation centers in smart charging and charging infrastructure.

2 Project Executive Summary

SCALE (Smart Charging Alignment for Europe) is a three-year Horizon Europe project that aims at preparing EU cities for mass deployment of electric vehicles and the accompanying smart charging infrastructure.

3 SCALE partners

List of participating cities:

- Oslo (NO)
- Rotterdam & Utrecht (NL)
- Eindhoven (NL)
- Toulouse (FR)
- Greater Munich Area (GER)
- Budapest & Debrecen (HU)
- Gothenburg (SE)

List of partners:

- (Coordinator) STICHTING ELAAD NL
- POLIS - PROMOTION OF OPERATIONAL LINKS WITH INTEGRATED SERVICES, ASSOCIATION INTERNATIONALE POLIS BE
- GoodMoovs NL
- Rupprecht Consult – Forschung & Beratung GmbH RC DE
- Trialog FR
- WE DRIVE SOLAR NL BV NL
- UNIVERSITEIT UTRECHT NL
- LEW Verteilnetz GmbH DE
- BAYERN INNOVATIV - BAYERISCHE GESELLSCHAFT FUR INNOVATION UND WISSENSTRANSFER MBH DE
- ABB BV NL
- Enervalis BE
- GEMEENTE UTRECHT NL
- Equigy B.V. NL
- SONO MOTORS GMBH DE
- Meshcrafts As (Current) NO
- Research Institutes of Sweden AB SE
- ETHNIKO KENTRO EREVNAS KAI TECHNOLOGIKIS ANAPTYXIS (CERTH) GR
- FIER Automotive FIER NL
- Emobility Solutions Kft. HU
- Serviced Office Belbuda Kft HU
- Enedis FR
- L'ASSOCIATION EUROPEENNE DE LA MOBILITE ELECTRIQUE (AVERE) BE

- Norsk elbilforening NO
- VDL ENABLING TRANSPORT SOLUTIONS BV NL
- Urban Electric Mobility Initiative UEMI DE
- Renault FR
- Chalmers University SE
- Polestar SE
- Hyundai NL

4 Deliverable executive summary

Key words

Electric vehicles, smart charging, bidirectional charging, V2X, ISO 15118, OCPP, OCPI, OpenADR, interoperability, congestion management, behind-the-meter, before-the-meter, balancing responsible, system balancing, aFRR, architecture

Summary

This deliverable, D2.4: V2G Product/Software, provides an in-depth overview of the collaborative development and integration of Vehicle-to-Grid (V2G) and smart charging infrastructure. It highlights the progress and outcomes of Task 2.4, presenting a blueprint for scalable, interoperable, and future-proof technologies designed to support the widespread adoption of electric vehicles (EVs) and their seamless integration into energy systems.

The document begins by setting the administrative context and offering an overview of the SCALE project, which brings together leading European stakeholders to advance and test smart charging and V2G ecosystems. In alignment with these objectives, this deliverable focuses on the collective contributions of partners in areas such as hardware innovation, software architecture, and interoperability testing. Each partner's expertise has been pivotal, from the development of cutting-edge V2G-compatible chargers to the refinement of communication protocols like ISO 15118-20 and OCPP, ensuring seamless operation across diverse systems.

The adaptability and modularity of the developed solutions are showcased through various use cases tailored to the operational and technical needs of both urban and rural pilot environments. For example, hardware innovations by ABB and We Drive Solar demonstrate the implementation of advanced V2G functionality, while collaborative testing with partners like Renault. Hyundai and Polestar highlight the challenges and breakthroughs in achieving interoperability. Additionally, Trialog’s work on protocol stacks and Enervalis’ focus on energy management tools illustrate how software advancements enable robust, real-time performance monitoring and grid integration.

Throughout the deliverable, particular attention is given to the importance of real-time data exchange, Key Performance Indicators (KPIs), and the integration of renewable energy resources. Lessons learned from pilots across Europe provide valuable insights into overcoming challenges such as standardization gaps, data handling complexities, and the need for user-friendly solutions. The document underscores the critical role of collaboration among partners, whose combined efforts have driven significant technological advancements and laid the foundation for future scalability.

By presenting a comprehensive overview of the technical, operational, and strategic developments achieved by the SCALE consortium, this deliverable highlights its significant contributions to Europe’s sustainable energy transition. It not only captures the milestones achieved but also outlines the pathways forward, ensuring that the work done within SCALE provides a robust platform for the ongoing evolution of V2G technologies and smart charging solutions.

5 List of abbreviations and acronyms

Acronym	Meaning
V2G	Vehicle-to-Grid
WP	Work Package
KPI	Key Performance Indicator
EV	Electric Vehicle
DSO	Distribution System operator
TSO	Transmission System Operator
CSP	Charging Service Provider
BSP	Balance Responsible Provider
eMSP	Electric Service Mobility Provider
OEM	Original Equipment Manufacturer
CPO	Charging Point Operator
CSP	Charging Service Provider
PV	Photovoltaic
EMS	Energy Management System
BESS	Battery Energy Storage System
OCPP	Open Charge Point Protocol
CSMS	Charging Station Management System
SCSP	Smart Charging Service Provider
CCS	Combined Charging System
TGP	Terra Gateway Pro
ECU	Electronic Control Unit
OBC	On-Board Charger

EVSE	Electric Vehicle Supply Equipment
EVI	Electric Vehicle Inlet
TLS	Transport Layer Security
PKI	Public Key Infrastructure
OpenADR	Open Automated Demand Response
BPT	Bidirectional Power Transfer
OCPI	Open Charge Point Interface
aFRR	Automatic Frequency Restoration Response
FCR	Frequency Containment Reserve
CBP	Crowd Balancing Platform

6 Purpose of the deliverable

Deliverable D2.4 focuses on the development and integration of the Vehicle-to-Grid (V2G) and smart charging product, hardware and software, which is a critical component of Task 2.4. This deliverable encompasses defining the software architecture, developing the necessary solutions, and thoroughly testing the implementation to meet the requirements set out in Task 2.3. The aim is to ensure seamless interaction between different software and hardware components, facilitating effective communication and interoperability between vehicles, chargers, and grid systems.

A core objective of this deliverable is to enable ISO15118-20 compliance in vehicles and charging stations, which is essential for ensuring secure and standardized communication for energy exchange. This standardization is crucial for interoperability across diverse systems and manufacturers. Additionally, the software platform will support the execution of various pilot projects by integrating monitoring tools for Key Performance Indicators (KPIs) within Work Package 4 (WP4). This will enable real-time tracking of system performance and ensure that the developed solutions align with project goals.

Additionally, Deliverable D2.4 describes an overview for monitoring. This will provide real-time insights into the system's performance, enabling proactive decision-making and ensuring that the developed solutions meet project goals. The collaborative overview of the software development process across all involved actors—ranging from innovation clusters to pilot implementation teams—ensures a smooth transition from development to interoperability testing. Moreover, overseeing the software development process across all participating stakeholders in the innovation cluster is crucial for a smooth transition into the interoperability testing phase under Task 2.5. This phase will validate the integration of developed components before entering the pilot implementation stage in Work Package 3 (WP3). By facilitating close collaboration among project contributors.

7 Different (system) roles and their connection to each other

This chapter shows all stakeholders and their needed connections to perform smart charging or V2G in any kind of interaction. Figure 1: Stakeholder roles overview gives an overview of all these stakeholders. In general, they can be divided into 2 domains.

Firstly, the energy domain is focused on managing and optimizing the flow of electricity within the grid. It is responsible for ensuring stability, efficiency, and reliability across the entire energy network. This domain addresses critical processes such as grid balancing, congestion management, and pricing dynamics. It plays a central role in enabling smart charging and Vehicle-to-Grid (V2G) by ensuring that energy supply meets demand in real-time.

One of the core functions of this domain is managing grid stability. When electric vehicles (EVs) charge, they draw a significant power from the grid, which can lead to imbalances if not properly managed. Similarly, during V2G sessions, when EVs feed energy back into the grid, it must be done in a way that supports grid needs, such as reducing congestion or stabilizing frequency.

Dynamic energy pricing and market participation are also key activities. For example, surplus energy from renewable sources like wind or solar can be utilized for smart charging during off-peak hours, ensuring cost-efficiency and reducing waste. Through close coordination between entities within this domain, energy usage and grid loads are optimized.

The energy domain communicates its requirements, such as grid capacity constraints or energy market prices, to the aggregator. This ensures that the mobility domain operates in alignment with grid conditions and market dynamics.

Secondly, the mobility domain focuses on facilitating the interaction between electric vehicles (EVs) and the infrastructure needed for their operation, such as charging stations and software platforms. This domain ensures that EV users have seamless access to smart charging services, while also enabling advanced functionalities like V2G.

In this domain, the primary concern is managing the charging process itself. Smart charging adjusts the timing and intensity of charging sessions based on grid conditions, user preferences, and energy prices. This ensures that EVs are charged efficiently and cost-effectively, while avoiding unnecessary strain on the grid. For instance, an EV might charge more aggressively during off-peak hours when electricity is cheaper or reduce charging speed during periods of high demand.

The mobility domain also includes the implementation of V2G, where EVs can act as mobile energy storage units. By feeding energy back into the grid, they help stabilize it and provide valuable services such as frequency regulation or emergency power during peak demand.

This domain is highly user-centric, prioritizing the needs of EV drivers while integrating with energy domain requirements. It uses data, such as charging behavior and vehicle energy demands, to coordinate with the aggregator. This coordination ensures that user convenience, grid stability, and market efficiency are all balanced effectively.

Both domains are interconnected and rely on seamless communication and data exchange to achieve efficient smart charging and V2G integration. The interactions between these components are essential for implementing the SCALE smart charging and V2G framework. More detailed information can be found in D1.4.

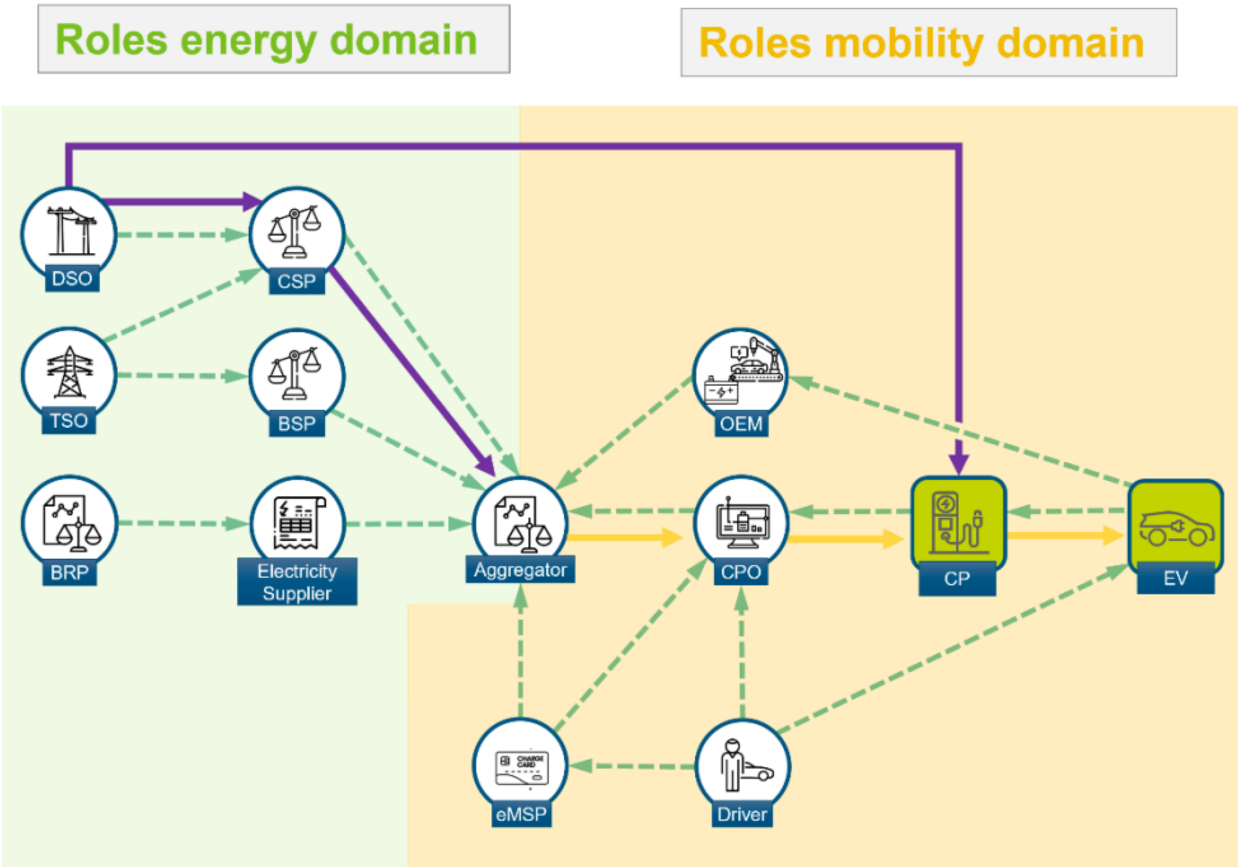


Figure 1: Stakeholder roles overview

Stakeholder overview

7.1.1 DSO

A Distribution System Operator (DSO) is responsible for managing the electricity distribution network at a local or regional level, usually handling the infrastructure that carries electricity from high-voltage transmission systems down to end users (such as homes, businesses, and other facilities).

As the energy industry shifts towards renewables and smart grids, DSOs play an increasingly vital role in managing decentralized power generation and consumption to create more resilient and sustainable energy systems.

7.1.2 TSO

TSO stands for Transmission System Operator. A TSO is responsible for the high-voltage electricity transmission network, which transports electrical power over long distances from power generation facilities (like power plants or large-scale renewable installations) to distribution networks or major consumers, such as industrial plants. They are crucial for ensuring a stable and interconnected electricity system.

TSOs will transition from managing linear power flows to orchestrating complex, multi-directional energy systems. Partnerships with DSOs, regulators, technology providers, and consumers will define their success in meeting the demands of a cleaner, smarter, and more resilient energy future.

7.1.3 CSP

CSP stands for Charging Service Provider. A CSP is a company or entity that provides access to and manages EV charging infrastructure for users. These providers often offer a range of services related to charging stations, including installation, operation, maintenance, and user interfaces for EV drivers. Future wise the CSP plays a crucial role in the EV ecosystem by offering services related to the accessibility, management, and optimization of EV charging infrastructure.

7.1.4 BSP

BSP stands for Balance Service Provider. BSPs play a critical role in maintaining grid stability and optimizing energy usage, particularly in systems that involve renewable energy sources and EV charging infrastructure. BSPs aggregate flexible energy resources, like EV chargers, batteries, and demand response participants, to provide services such as frequency regulation, reserve power, and voltage control.

BSPs are essential for enabling V2G services, where EVs can discharge stored electricity back into the grid during peak demand periods, earning revenue for EV owners while supporting the grid. BSPs manage smart charging schedules for EVs, ensuring that vehicles charge during off-peak hours or when renewable energy is abundant, thereby reducing costs and grid strain.

They provide Increased grid stability in the face of renewable energy variability, enhanced energy efficiency and reduced peak demand costs and support for the transition to a low-carbon energy system by integrating EVs and renewables.

7.1.5 BRP

BRP stands for Balance Responsible Party. A BRP is a market participant responsible for ensuring that the energy supply and consumption within its portfolio are balanced in real-time, which is critical for maintaining grid stability. Here's how BRPs fit into the EV and energy ecosystem.

- **Managing EV Charging**
  - BRPs incorporate EV charging demand into their portfolio forecasts.
  - With smart charging technologies, BRPs can adjust EV charging schedules to optimize grid stability and minimize energy procurement costs.
- **Vehicle-to-Grid (V2G) Coordination**:
  - BRPs leverage EVs capable of V2G technology to discharge energy back to the grid during high demand, reducing imbalance costs.
- **Demand Response Programs**:
  - BRPs may incentivize EV owners to participate in demand response programs, using flexible EV charging as a tool to balance the grid.

7.1.6 Electricity supplier

Electricity suppliers in the EV market are central to smart charging and V2G integration, leveraging technologies that manage when and how EVs charge and discharge energy. This allows them to optimize grid operations, balance energy demand and supply, and support the transition to a more sustainable and resilient energy system. By offering dynamic pricing, incentivizing smart charging behaviour, and enabling V2G, they contribute significantly to grid stability and the integration of renewable energy.

By providing smart charging infrastructure, suppliers help manage when and how EVs draw power. Suppliers can control charging through smart meters and charging stations, either directly or through third-party services, to avoid overloading the grid at peak times.

7.1.7 Aggregator

Aggregators play a critical role in the EV market and grid stability by managing the charging and discharging of EVs through smart charging and V2G technologies. They ensure that EVs provide flexibility to the grid, helping balance supply and demand, integrate renewable energy, and support grid resilience. By coordinating large numbers of EVs as flexible resources, aggregators help optimize energy consumption, reduce grid congestion, and enable the transition to a more sustainable and reliable energy system.

7.1.8 EMSP

An eMSP (electric Mobility Service Provider) is a type of company operating in the electric vehicle (EV) and energy market. Its main role is to provide services to EV drivers that make charging more convenient and accessible.

7.1.9 OEM

An OEM (Original Equipment Manufacturer) plays a crucial role in the energy transition, particularly in the context of V2G (Vehicle-to-Grid) and smart charging technologies. These technologies are key to enabling a more sustainable and flexible energy system, leveraging EVs as assets in energy storage and grid balancing. The OEM needs to collaborate to multiple other stakeholders which are described above to interact

7.1.10 CPO

CPO (Charge Point Operator) plays an essential role in the energy transition, particularly in the development and implementation of V2G (Vehicle-to-Grid) and smart charging technologies. EV CPOs are responsible for owning, managing, and maintaining the physical charging infrastructure, and their involvement in V2G and smart charging is critical for enabling efficient energy flow between electric vehicles and the grid. The CPO plays an important role in these features by adjusting charging sessions to ensure grid balance, reduce peak demand and optimize green energy usage, price optimization, ...

The role of the CPO in the energy transition is vital—they provide the physical infrastructure, manage energy interactions, and enable the seamless integration of V2G and smart charging into the grid. By doing so, they help electric vehicles evolve from being just consumers of electricity to becoming active participants in energy management, playing a key role in the stability and sustainability of the power grid.

7.1.11 Driver

EV drivers are pivotal in the energy transition as their participation in V2G and smart charging helps create a more flexible, stable, and renewable-friendly grid. Financial incentives, environmental benefits, battery management, energy independence, and access to advanced technology are powerful motivators for drivers to actively engage in these transformative technologies. Their participation not only benefits the energy system as a whole but also brings personal gains in the form of cost savings and convenience.

Stakeholder interconnections

The SCALE project architecture is built around a collaborative ecosystem of stakeholders, each with distinct roles that complement one another in managing energy flow, enhancing electric vehicle (EV) integration, and stabilizing the grid. The main stakeholders include DSOs, TSOs, CSPs, BSPs, BRPs, electricity suppliers, aggregators, eMSPs, OEMs, CPOs, and EV drivers. Below is an overview of how they interact and contribute to the project's architecture:

1. **TSO-DSO Interaction**: TSOs manage high-voltage transmission networks, while DSOs handle local electricity distribution. TSOs and DSOs collaborate to ensure grid stability, especially with multi-directional energy flows involving renewables and EVs. Their combined efforts enable decentralized energy management and effective power transmission.
2. **BSP and BRP Roles in Balancing the Grid**: BSPs aggregate flexible energy resources to provide grid balancing services like frequency regulation. BRPs ensure energy supply and demand are balanced in real-time. BRPs work closely with BSPs to adjust consumption and manage surplus generation during peak times.
3. **CSP, CPO, and Aggregator in EV Charging Infrastructure**: CSPs offer services for EV charging stations, while CPOs manage physical charging infrastructure. Aggregators coordinate multiple EVs for balancing supply and demand using smart charging and V2G. Aggregators act as intermediaries between drivers, CSPs, and grid operators.
4. **Electricity Suppliers and Smart Charging**: Electricity suppliers provide energy to users, including EV drivers, and promote smart charging and V2G services. They work with CPOs, CSPs, and BRPs to optimize procurement and stability through dynamic pricing. Suppliers' interactions facilitate the use of smart meters and charging schedules.
5. **OEM and eMSP in User-Centric Solutions**: OEMs supply EVs with V2G and smart charging technology, enhancing energy use optimization. eMSPs provide services to make EV charging convenient and collaborate with other stakeholders to ensure infrastructure reliability.
6. **EV Drivers as Active Participants**: EV drivers play a crucial role in the energy transition by participating in V2G and smart charging activities. They partner with Aggregators, CSPs, and eMSPs to use their vehicles as mobile energy assets, benefiting both themselves and the grid.
7. **Architecture of the SCALE Project**: The SCALE project integrates various stakeholders for grid resilience, sustainable energy use, and EV integration. Data exchange and communication flow between stakeholders like TSOs, DSOs, and Aggregators, with Aggregators central to bridging the energy and mobility domains. Data exchange relies on protocols like OpenADR and OCPI, which are not yet fully standardized. Energy flows from TSOs to DSOs, then to CPOs and CSPs, with BSPs and BRPs maintaining balance. V2G and smart charging enable EVs to become active grid resources, contributing to a flexible, resilient energy system.

The interactions between these stakeholders form an ecosystem that aims to make the energy grid more flexible, resilient, and capable of integrating renewable energy at a larger scale. This architecture is designed to support a more sustainable energy system by leveraging advanced technologies, optimized charging infrastructure, and active participation from EV users.

8 Architecture topology

General architecture

Figure 2 gives an overview of the generic SCALE system architecture which can be used in default use cases. This architecture is a solid foundation for smart charging and V2G charging. The generic architecture can be used and tailored regarding to specific use-case needs. All kind of stakeholders (described in chapter 7) can be added in the loop based on the specific role and use case. In general, all the stakeholders and their function will stay the same as well as how they are connected and interact with each other, including the protocols.

This architecture serves as a default framework facilitating communication, data exchange, and operational coordination among various stakeholders in the EV charging infrastructure that can be customized for specific needs, such as incorporating renewable energy sources, supporting vehicle-to-grid energy sharing (where EVs provide power back to the grid), or managing high-demand situations. Overall, it provides a structured approach to ensuring that EV charging is efficient, sustainable, and aligned with grid requirements.

At its core, the system ensures that EVs can be charged efficiently, energy is managed effectively, and all participants work together to provide a reliable and user-friendly experience.

The vehicle manufacturer, or OEM, communicates directly with the EV using proprietary protocols to handle vehicle-specific functions such as diagnostics and updates. E-Mobility Service Providers (eMSPs) enable EV owners to access charging stations and facilitate payment services. These providers work closely with Charge Point Operators (CPOs), who are responsible for managing the charging stations, ensuring they operate correctly and stay connected to the larger system.

The Energy Management System (EMS) plays a crucial role by overseeing energy distribution at the charging site. It balances energy demand with supply, ensuring that the site operates efficiently without straining the power grid. The Smart Charging Service Provider (SCSP) works alongside the EMS to optimize charging schedules, helping to reduce costs and align charging times with periods of abundant or renewable energy availability. This optimization also involves coordination with the Distribution System Operator (DSO), which manages the power grid's stability and prevents overloads.

The flow of energy begins at the grid, controlled by the DSO, and travels to the charging stations and then to the EVs. Simultaneously, data flows between stakeholders. For instance, the CPO communicates with the eMSP to coordinate access and payments, and with the EMS to manage the technical aspects of charging. The SCSP exchanges data with the EMS and the DSO to adjust charging based on real-time grid conditions and energy supply.

Standards and protocols ensure smooth communication within this system. ISO 15118-20 governs the interaction between the EV and the charger, enabling secure and intelligent charging. The Open Charge Point Protocol (OCPP) standardizes communication between chargers and the systems managing them, while the Open Charge Point Interface (OCPI) allows CPOs and eMSPs to exchange data, ensuring interoperability and ease of use for EV drivers.

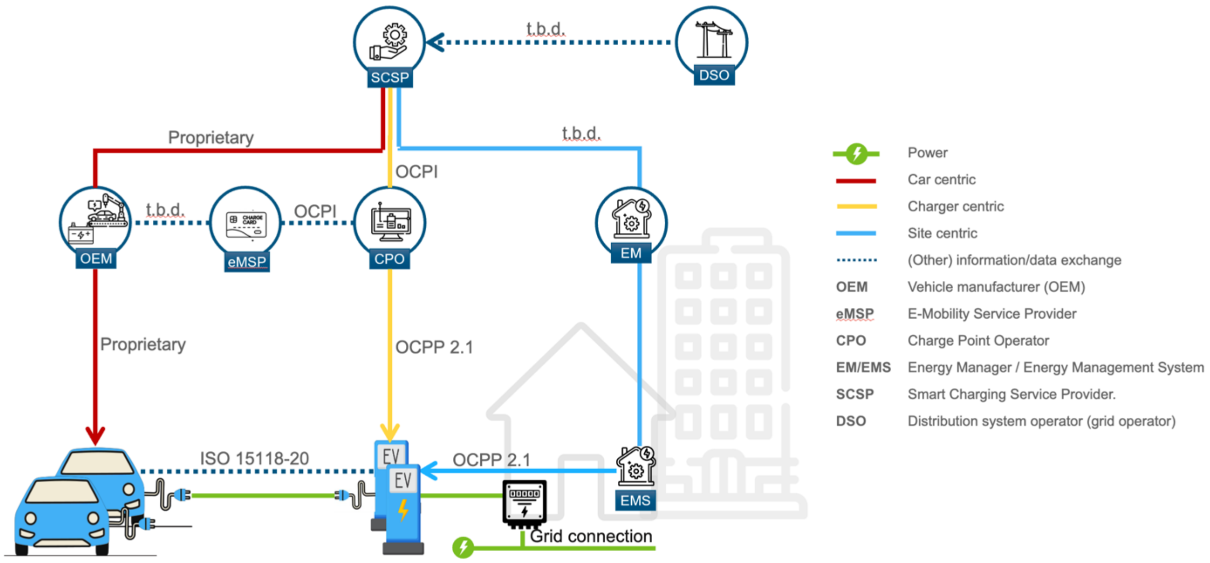


Figure 2: Stakeholder architecture overview

Tailoring to specific clusters

When the architecture is adapted to a specific use case, such as home charging, public charging, or workplace charging, notable shifts in focus and complexity emerge. The roles of stakeholders evolve significantly depending on the scenario. For instance, in public charging, Charge Point Operators (CPOs) and e-Mobility Service Providers (eMSPs) play a critical role in enabling interoperability and managing operations. In contrast, these roles diminish or disappear entirely in home charging, where the Energy Management System (EMS) becomes central, ensuring efficient energy distribution and balancing within the household. New stakeholders, like building managers or facility operators, may become relevant in workplace or fleet charging scenarios.

The complexity of the communication chain also changes with the use case. Home charging typically involves a simpler communication setup, primarily between the EV, the charging station, and the local EMS. Conversely, public charging involves a more extensive network, requiring standardized protocols and communication between multiple entities, such as CPOs, SCSPs (Smart Charging Service Providers), and Distribution System Operators (DSOs). This increased complexity ensures that large-scale systems can function effectively and manage demand across multiple charging points.

Energy management priorities also differ based on the use case. Home charging focuses on optimizing energy use within the household, such as prioritizing solar energy or avoiding grid overload during peak usage. Public charging, on the other hand, emphasizes grid stability and managing peak loads across multiple charging stations. Workplace charging often integrates energy management with business needs, such as optimizing fleet operations or utilizing surplus energy from onsite renewable sources.

The use of specific standards and protocols is tailored to the scenario. Home charging benefits from standards like ISO 15118-20, which enables secure, automated charging sessions, and OCPP 2.1, which facilitates communication between the charger and the EMS. In public charging, interoperability is a priority, with protocols like OCPI ensuring seamless roaming and communication between networks and service providers. These tailored standards ensure that each use case meets its specific operational needs.

Smart charging strategies also vary with the use case. In home charging, the focus is on reducing costs by aligning charging with off-peak electricity rates or maximizing the use of renewable energy. Public charging leverages smart strategies to balance demand across the grid and avoid overloads during high-demand periods. Workplace charging integrates similar strategies while also considering company-specific energy goals and fleet management requirements.

The degree of user autonomy differs significantly as well. In home charging, users have more control over their charging decisions, such as setting schedules or prioritizing renewable energy use. In public charging, user control is limited, with much of the operation relying on the coordination of service providers and operators to ensure a smooth experience.

Finally, scalability and interoperability become critical factors in larger-scale use cases like public and workplace charging, where the system must handle multiple charging stations, providers, and vehicle types. In smaller-scale applications like home charging, the focus is more on convenience and integration with local energy systems rather than scalability.

Overall, adapting the architecture to a specific use case results in a shift in focus, stakeholder involvement, and complexity. Each use case has unique requirements, and tailoring the architecture ensures these needs are met, whether it's ensuring user convenience and energy efficiency for home charging or managing large-scale grid stability and network interoperability for public charging scenarios.

8.1.1 Home charging

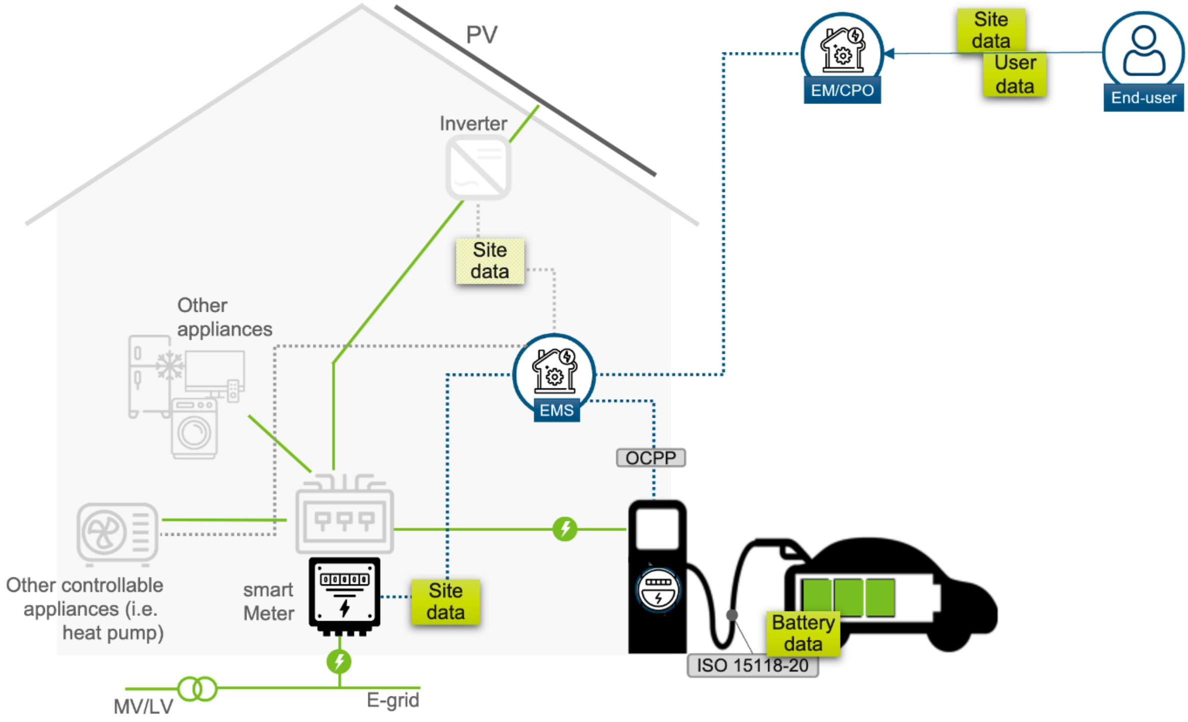


Figure 3: Home charging architecture

At the core of this system is the Energy Management System (EMS), which orchestrates the flow of energy between the home, the EV, the solar PV system, the Charge Point Operator (CPO), and the grid. The EMS acts as the brain of the system, ensuring that energy is managed efficiently, cost-effectively, and in alignment with user preferences. It continuously gathers data from various components, such as the solar inverter, smart meter, EV charger, EV battery, and the CPO, to make real-time decisions about energy distribution.

The solar PV system generates electricity, which the EMS directs to where it is most needed—whether to power the house, charge the EV, or export to the grid. When solar generation is high, the EMS can prioritize charging the EV battery or even powering other controllable appliances like heat pumps. During periods of low energy production or high household demand, the EMS can switch to discharging the EV battery back into the home or grid using Vehicle-to-Grid (V2G) technology, providing flexibility and support for both the home and the wider energy network.

The Charge Point Operator (CPO) plays a key role in this system by enabling advanced external management and data exchange. The CPO communicates with the EMS to provide information about grid conditions, electricity pricing, and potential demand-response requests. It also integrates user preferences and energy provider policies to optimize the charging process. For example, the CPO might signal the EMS to prioritize charging during off-peak hours or reduce grid reliance during peak demand periods. The CPO ensures the entire system operates efficiently and aligns with broader grid needs while maintaining a user-focused approach.

The smart meter provides the EMS with detailed data on energy usage and the interaction between the home and the grid. This helps the EMS decide when to charge or discharge the EV battery and when to use or export solar power. The EV charger, under the control of the EMS, operates in both charging and V2G modes, depending on energy availability and user preferences. The EMS carefully monitors the EV battery's state of charge and health, ensuring safe and optimized operations.

The user interacts with the system through an app or interface, setting preferences such as charging schedules, desired battery levels, and V2G availability. These inputs are relayed to the EMS and CPO, which integrate them into their optimization strategies. By balancing user needs with grid requirements, the system ensures maximum convenience for the user while contributing to grid stability.

In summary, the EMS, supported by the CPO, enables dynamic, intelligent energy management. It reduces costs by optimizing when and how energy is used, maximizes sustainability by leveraging solar power and V2G functionality, and provides a seamless user experience. The integration of these components creates a smart, efficient, and environmentally friendly energy system.

8.1.2 Depot charging

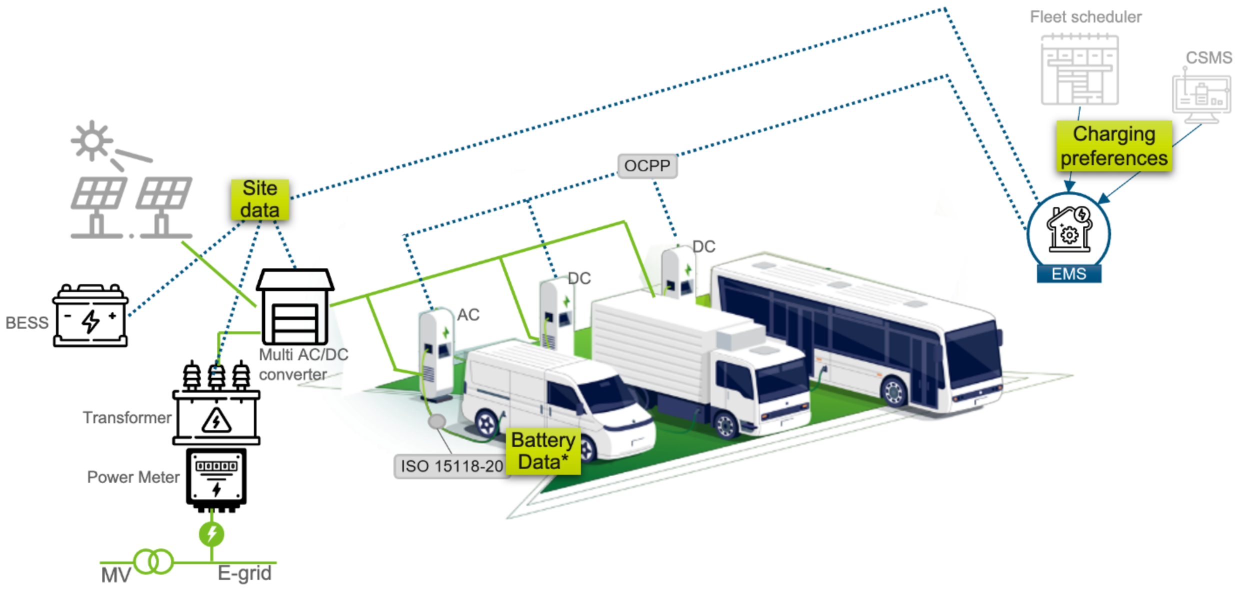


Figure 4: Depot charging architecture

This system in Figure 4 represents a smart EV charging and Vehicle-to-Grid (V2G) setup for a fleet depot. At the core of the system is the Energy Management System (EMS), which coordinates the energy flow between the various components, including renewable energy sources, energy storage, the EV chargers, the fleet vehicles, and the grid. The EMS uses real-time data from these components to optimize energy usage, ensuring efficient charging schedules, reduced costs, and support for grid stability.

The solar PV system provides renewable energy to the depot. The EMS determines how this energy is used, whether to directly charge vehicles, store it in the Battery Energy Storage System (BESS), or send excess energy back to the grid. The BESS acts as an energy buffer, storing energy during periods of high solar generation or off-peak grid electricity rates. It can discharge energy when needed, such as during periods of high demand or insufficient solar generation, to power the depot or support the grid.

EV chargers at the depot are managed by the EMS, which communicates with them using protocols like OCPP and ISO 15118-20. The chargers can either charge the fleet vehicles or, in V2G mode, allow the vehicles to discharge stored energy back to the grid or depot. The EMS takes into account real-time battery data from the vehicles and charging preferences provided by the fleet scheduler. This ensures vehicles are charged to meet operational requirements while allowing for flexibility in energy usage.

The fleet scheduler and Charging Station Management System (CSMS) provide key inputs to the EMS, such as departure times, required charge levels, and infrastructure monitoring. The EMS uses this information to prioritize charging schedules and align energy use with fleet demands. Meanwhile, the power meter and transformer regulate and monitor the flow of energy between the depot and the grid, enabling the EMS to make informed decisions about when to draw power from or export energy to the grid.

This system's capabilities extend beyond simply charging vehicles. It enables smart energy optimization by balancing energy generation, storage, and consumption. It reduces costs by prioritizing the use of renewable solar energy and off-peak electricity while contributing to grid stability through V2G functionality. By integrating these components, the system creates a sustainable and efficient solution for managing energy at a fleet depot, ensuring vehicles are operational while minimizing environmental impact and energy costs.

8.1.3 Public charging

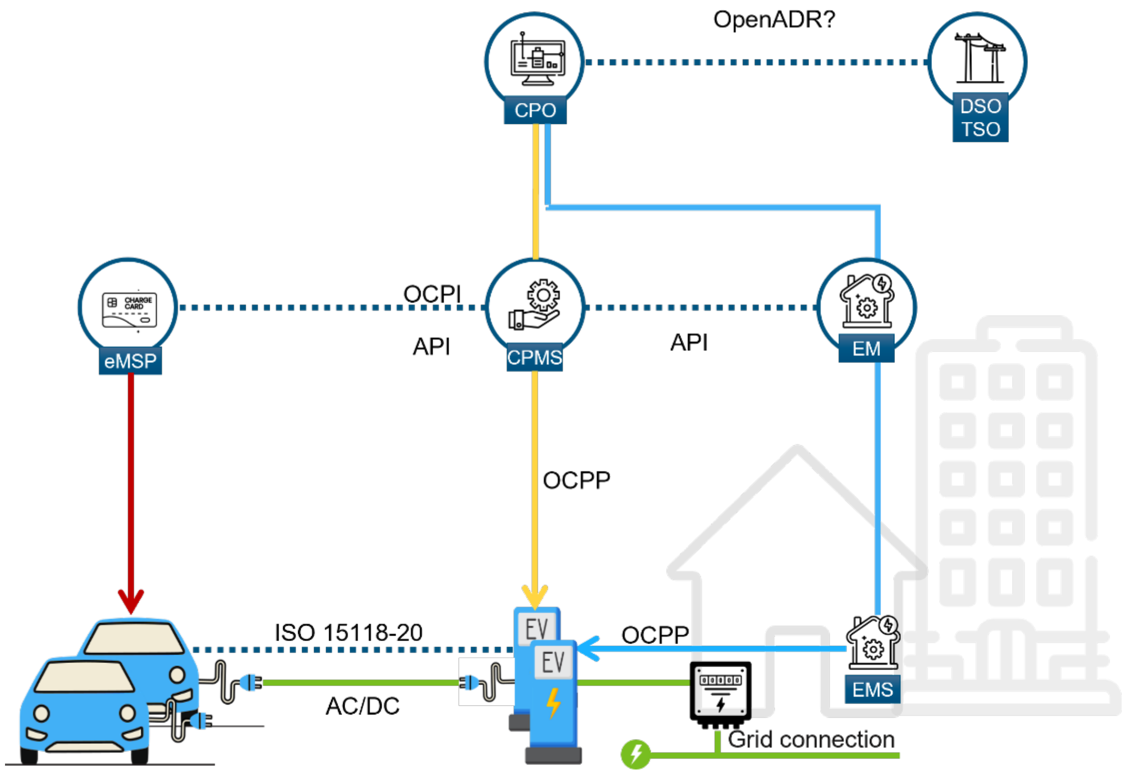


Figure 5: Public charger architecture

This diagram in Figure 5 represents an EV charging system in a public environment, utilizing smart charging and Vehicle-to-Grid (V2G) capabilities. The system integrates various components to optimize energy usage, ensure seamless communication, and support both grid and user needs.

At the heart of the system is the Charge Point Management System (CPMS), which acts as a central platform to manage and monitor the operation of public EV chargers. The CPMS communicates with the Charge Point Operator (CPO) via APIs and uses the Open Charge Point Protocol (OCPP) to control individual EV chargers. These chargers can operate in both standard charging and V2G modes. Through the V2G functionality, the chargers can send energy from EV batteries back to the grid or to support local energy demands, depending on requirements set by the system or external signals.

The system interacts with the Energy Management System (EMS) to ensure charging is aligned with energy availability and grid conditions. The EMS integrates site-level energy data, managing the grid connection and coordinating with Distributed System Operators (DSO) or Transmission System Operators (TSO). These operators provide information about grid constraints and energy demands, enabling the EMS to make real-time decisions to stabilize the grid and optimize charging schedules.

The eMobility Service Provider (eMSP) connects EV drivers to the system by managing user accounts, payment processing, and providing access to public chargers. Through the Open Charge Point Interface (OCPI), the eMSP exchanges data with the CPMS, ensuring a seamless user experience. Drivers use their credentials (e.g., charge cards or apps) to start charging sessions, and their preferences and requirements are communicated to the CPMS for execution.

At the charger level, ISO 15118-20 ensures secure communication between the EV and the charger. This protocol allows the exchange of detailed battery data, such as state of charge and V2G capabilities, enabling the system to tailor charging or discharging operations based on vehicle and user needs. AC/DC converters within the chargers manage the flow of energy efficiently to match the requirements of the EVs and the grid.

This public charging system supports smart charging by aligning energy consumption with off-peak grid times, renewable energy availability, pricing and user schedules. Its V2G capabilities allow it to discharge energy back into the grid during peak demand, providing grid stabilization and reducing strain on the energy network. This integration of components and protocols ensures a robust, efficient, and user-friendly charging experience while contributing to a more sustainable energy ecosystem.

8.1.4 Office charging

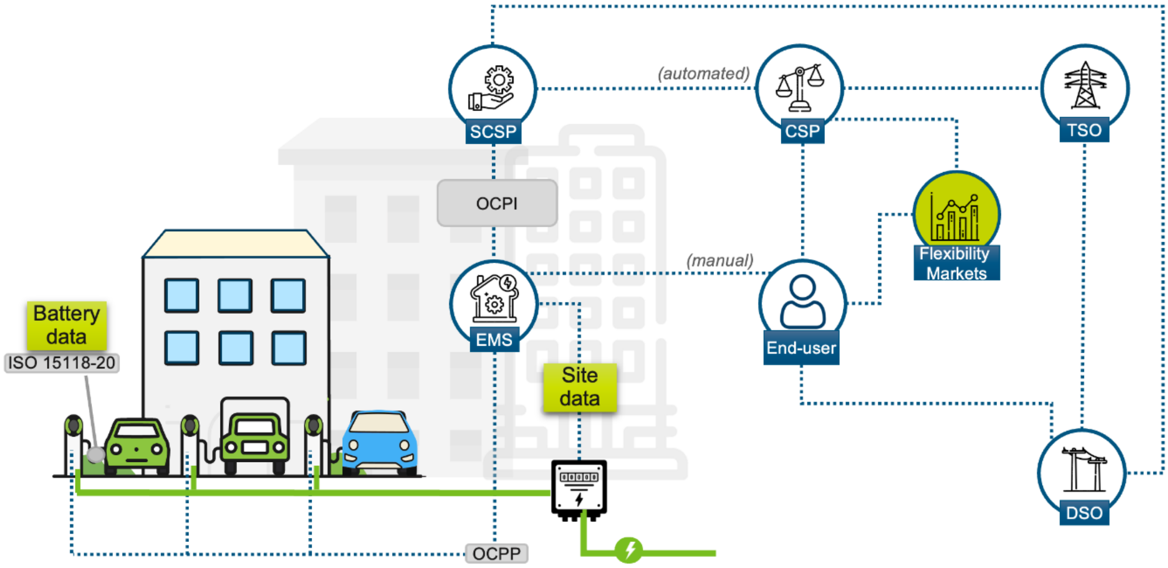


Figure 6: Office charging architecture

This system represents an EV charging setup in an office building, incorporating smart charging and Vehicle-to-Grid (V2G) capabilities. At the core is the Energy Management System (EMS), which manages energy flows between the office building, the EV chargers, the vehicles, and external energy systems like the distribution grid and flexibility markets. The goal is to optimize energy usage, reduce costs, and support grid stability while meeting the charging needs of office employees.

The EMS collects and uses site data from a smart meter to monitor energy consumption, grid interaction, and local renewable energy production. It communicates with the EV chargers through the Open Charge Point Protocol (OCPP) to control charging and V2G operations. The EVs, equipped with ISO 15118-20 communication protocols, share battery data with the EMS, such as their state of charge, charging capacity, and V2G readiness. Based on this data and user preferences, the EMS determines when and how to charge the vehicles or use V2G to send energy back to the building or grid.

The system integrates optionally with Flexibility Markets to provide energy services. For example, during peak grid demand, the EMS can discharge energy from connected EVs to support the grid, earning revenue or credits for the office. This interaction is supported by the Distribution System Operator (DSO) and Transmission System Operator (TSO), who provide grid condition data and market signals. Additionally, Smart Charging Service Providers (SCSPs) and Charge Service Providers (CSPs) interact with the EMS to automate decisions and offer services like optimal charging schedules based on grid tariffs and energy availability.

Office employees, as end users, interact with the system through manual inputs, setting preferences like desired charge levels and departure times. This information is integrated by the EMS to ensure the vehicles are charged appropriately while participating in energy optimization processes.

In summary, this system leverages smart charging and V2G technology to balance energy demands, reduce costs, and support sustainability. The EMS acts as a central coordinator, aligning vehicle charging needs with the building's energy strategy and external grid requirements, making the office environment both energy-efficient and user-friendly.

Architecture flexibility

The architecture developed for the V2G product/software is inherently modular and flexible, allowing it to be adapted to the specific requirements of various use cases and pilot sites. This adaptability ensures that the system can address the unique operational, regulatory, and technical constraints of each deployment environment. Building upon the foundation outlined in Chapter 7, which details the core architecture, Chapter 8 emphasizes how this framework can be customized to meet localized demands.

The architectural design presented in Deliverable D1.4 establishes a robust foundation that is intentionally designed for flexibility and scalability. This design supports different market roles and ensures interoperability through standard protocols such as ISO15118-20 and OCPP. For instance, pilot sites with advanced grid infrastructure can leverage the full capabilities of ISO15118-20 communication protocols for seamless bi-directional energy transfer. Conversely, in regions with limited grid capabilities, the system can be scaled down to prioritize basic smart charging features while maintaining interoperability standards. This dynamic scalability is made possible through modular software components that can be activated or deactivated based on site-specific needs.

The practical application of this adaptable architecture is evident in the use cases outlined in Deliverable D3.1. Each pilot site, whether in urban centers like Rotterdam/Utrecht or rural areas such as Budapest, employs a tailored configuration of the system to meet local requirements. For example, urban environments with high EV density may integrate sophisticated load balancing algorithms to manage congestion, whereas rural sites might emphasize grid stability and basic energy optimization features.

Additionally, the integration of monitoring tools for Key Performance Indicators (KPIs) in WP4 allows for real-time adjustments in system performance to suit the operational demands of each pilot site. This is further enhanced by compliance with regional regulatory standards and grid codes, achieved by configuring the software modules accordingly, ensuring smooth deployment and operation.

Through this tailored approach, the V2G architecture supports diverse use cases ranging from residential smart charging solutions to large-scale fleet energy management, thereby maximizing the scalability and impact of the technology across different pilot sites.

9 Hardware

System integration

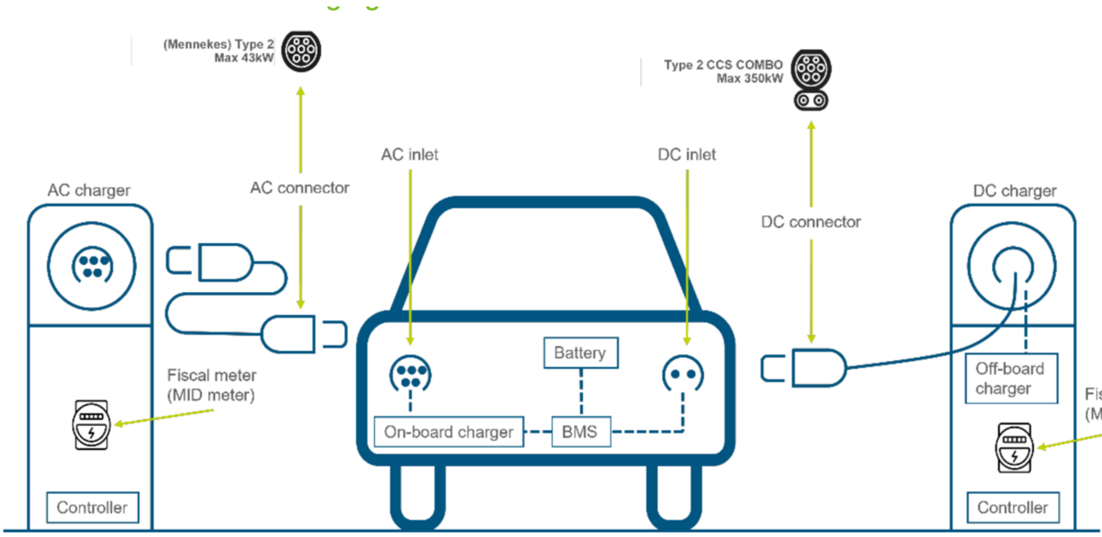


Figure 7: Car and charger system integration

The charging ecosystem for an electric vehicle (EV) involves several components and interactions. An EV has two primary inlets: an AC inlet and a DC inlet. The AC inlet is used for slower charging where AC power is delivered to the EV and converted to DC by the on-board charger. The DC inlet allows for faster charging by bypassing the on-board charger and directly delivering DC power to the battery. The battery stores energy to power the vehicle, and the Battery Management System (BMS) ensures safe and efficient operation.

An AC charger supplies AC power to the EV. It includes a fiscal meter (MID meter) for measuring energy consumption accurately for billing purposes and a controller to manage the charging process. The AC connector links the AC charger to the EV through the AC inlet. Charging with AC is slower as it depends on the on-board charger to convert the power to DC.

A DC charger, on the other hand, supplies DC power directly to the EV battery. It includes an off-board charger for converting AC power to DC externally, a fiscal meter for billing, and a controller to regulate the charging process. The DC connector links the DC charger to the EV through the DC inlet. DC charging is faster due to its direct delivery of power to the battery.

The charging process relies on standards for compatibility. Type 2 (Mennekes) is a common standard for AC charging, supporting up to 43 kW. CCS Combo (Combined Charging System) supports both AC and DC charging, with DC charging speeds up to 350 kW.

Smart charging enables real-time communication between the EV, charger, and the grid. It optimizes charging by adjusting speed based on grid demand, time-of-use tariffs, and renewable energy availability. This helps reduce costs and align charging with sustainable energy practices.

Vehicle-to-Grid (V2G) technology allows bidirectional energy flow, where the EV can supply energy back to the grid. This supports grid stabilization during peak demand and enables the EV to act as a storage system for renewable energy, feeding it back when needed.

In summary, AC charging is slower and uses the on-board charger, while DC charging is faster and bypasses it. Smart charging and V2G enhance the system by integrating grid interactions and renewable energy, making EVs a key part of sustainable energy ecosystems.

9.1.1 ABB charger

For SCALE project, ABB designed ABB Terra Nova 11 chargers with Combined Charging System (CCS) which is suitable for European EV market to use for DC charging and have the capability to charge and discharge the EV battery when required to do so.

Terra Nova 11 charger has a compact design thanks to its innovative silicon carbide power electronics technology with a low weight of below 25kg (excluding the charge cable and cable holder) and low noise level (< 45dBA) and can also be integrated with ABB/Enervalis Terra Gateway Pro energy management systems. The charger can be potentially used by Charge Point Operators (CPOs), aggregators, companies and households to participate in the energy market via its V2G functionality.

Figure 8: Front View of ABB Terra Nova 11 V2G Charger

The front of the charger surface includes the RFID reader that can be used for authorization to start and stop of a charge/discharge session. (The discharge signal needs to come from the charger operator). An LED strip to show the status and a multi-functional charge button.

Figure 9: Side View of ABB Terra Nova 11 V2G Charger

From the side of charger perspective, the bracket to mounting and ventilation is more visible which is also integrated with the gun holder. The design of the bracket is to make sure that heat is ventilated efficiently via its integrated ventilation fans and grid cover.

Figure 10: Exploded View

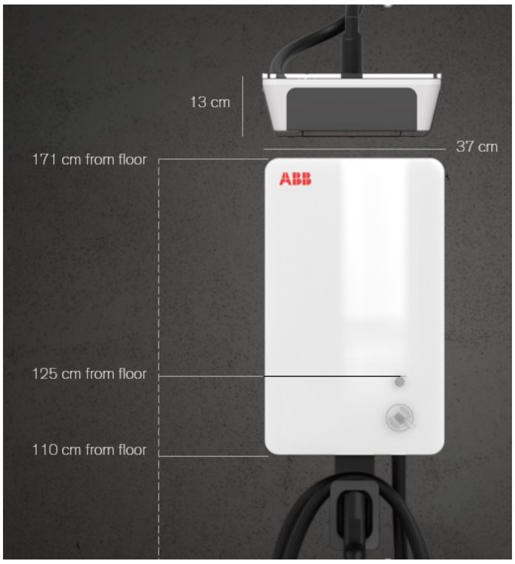
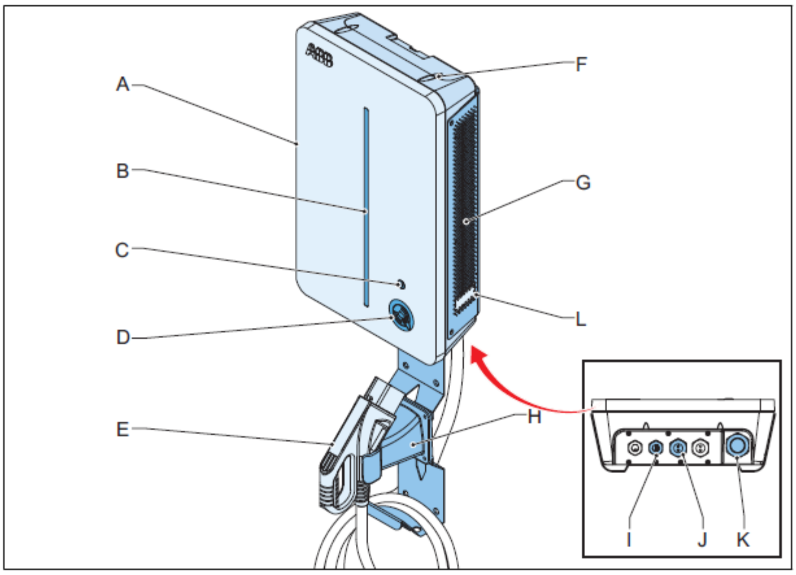


Figure 11: Clean Installation View



A	Cabinet cover	G	Mounting bracket
B	LED indicator	H	EV charge cable holder
C	Multi functional charge button	I	Opening for the Ethernet cable
D	RFID reader	J	Opening for the AC input cable
E	EV charge cable	K	Opening for the EV charge cable
F	Enclosure	L	Type plate

Part	Function
Cabinet cover	To prevent a user to access the installation and maintenance parts of the EVSE
LED indicator	To show the status of the EVSE and the charge/discharge session
Multifunctional charge button	To start or stop a charge/discharge session and to select a charge mode
RFID reader	To authorize the start or stop of a charge/discharge session with an RFID card
EV charge cable	To conduct the charge from the EVSE to the EV
Enclosure	To reduce the accessibillity of unqualified persons to the inside of the EVSE
Mounting bracket	To install the EVSE to a wall or on a pedestal
EV charge cable holder	To keep the EV charge cable
Openings	Openings for the cables that go into the EVSE
Type plate	To show the identification data of the EVSE.

Figure 12: Overview of the charger from Outside

To start a charge/discharge session, connect the EV charge cable to the EV, authorize the session using an RFID card or owner-provided option if required, and press the charge button or use the owner's app. For bi-directional charging supported by ISO15118-20, the operator can start discharge remotely via OCPP.

To stop a session, authorize disconnection via RFID or app, unplug the cable, and stow it. If the charger is in free vending mode, RFID authorization can be skipped.

The safety related description, installation, maintenance, cleaning and troubleshooting of ABB Terra Nova 11 charger is not written here due to the consideration of the length of the report and lower relevance to smart charging topic. However, the information is available and has been shared with charge operator partners who are using ABB chargers for the sites, namely Emobilty Solutions and Current ECO.

This product is designed for the SCALE project. Being state of the art supporting V2G discharge sessions and injecting energy back into the grid. This opens a lot of opportunities to use the EV battery as a flexible asset to perform quite some flexibility services before the meter and after the meter. So more specifically this can add value in grid optimization as well as local optimization at a specific location. More information about flex services and optimization can be found in D3.2.

Figure 13 shows the lab environment where the charger has been tested for its V2G functionalities including the ISO15118-20 protocol which in this case is simulated to perform a full test. More details on the interoperability testing can be found in D2.5.

Figure 13: Test setup of V2G charger in the ABB lab environment

This charger can be added to existing charging plaza's and connected to the same CPO or back-end system. An example of this are the pilot sites in Hungary: the charger will be integrated to the already existing ecosystem. This will significantly increase the flexibility by the energy services which can be delivered with V2G charging. More information about the use cases and pilot sites can be found in D3.1 and D3.2.

9.1.2 Terra Gateway Pro

9.1.2.1 General overview

The ABB E-Mobility Terra Gateway Pro (TGP) is an industrial PC which performs as a state-of-the-art EMS system.

Figure 14: ABB Terra Gateway Pro EMS system

Enervalis develops the software for this device to perform onsite energy management where several types of assets are located at company sites, charging depots, highway charging, etc,... Typical assets the TGP monitors and controls are:

- AC and DC chargers
- Stationary battery systems
- Solar installations
- Measurement equipment to measure and uncontrollable loads and the grid connection point

If this developed solution is projected to the Hungarian and VDL use cases, the architecture is tailored to suit the pilot sites needs. The same stakeholders as in Chapter 7 are included in these pilot sites. Normally the charging stations will directly communicate with the CPO to control the charging sessions. This is a dumb system without any opportunities for energy management, smart charging or V2G charging.

9.1.2.2 Practical pilot site implementations

9.1.2.2.1 Hungarian pilot sites

Without any smart charging or V2G solutions the pilot sites are schematically presented in an overview in Figure 15. All assets are present, but they are working stand-alone without any interaction with each other and working independently. In practice, this means no energy flows are managed and a lot of potential is lost. If there is a PV-system, battery system and (V2G) chargers there is a lot of flexibility present at location to use in a clever way to optimise energy flows and perform several energy services.

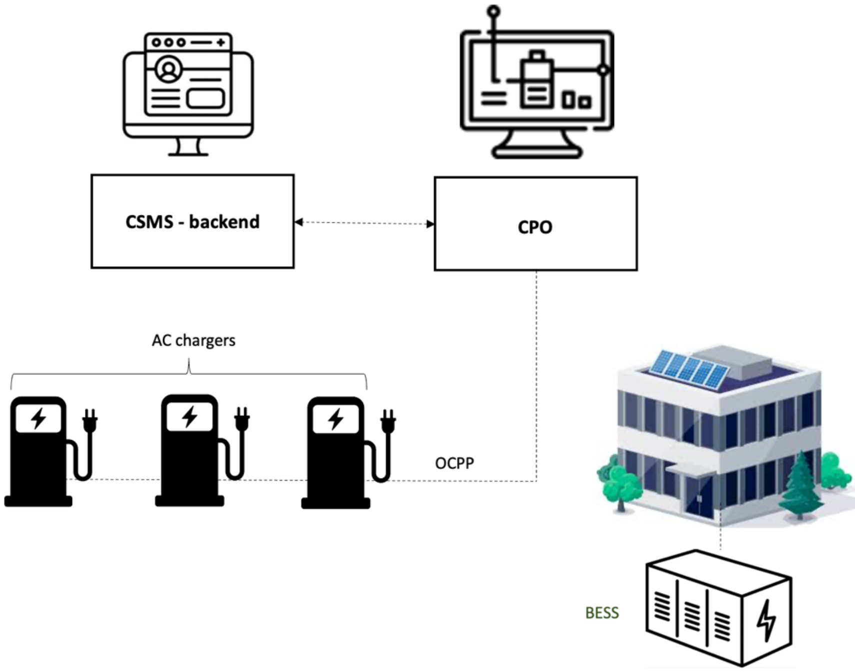


Figure 15: Schematic overview without smart charging and V2G solutions

By integrating the TGP in the architecture as a man-in-the-middle solution, Enervalis will control the charging sessions, battery systems and measure the solar system and other assets. The OCPP connection between the charger and the CPO will be rerouted from the charger to the TGP, and the TGP will forward the information to the CPO.

The TGP has a OCPP broker running in software, which intercept the messages of the chargers and forwards them to the CPO. In the standpoint of the charger and CPO it acts like a direct connection because the messages are just forwarded by the TGP. By intercepting the messages, the TGP receives all the detailed information of all active charging sessions and can also control the charging sessions if needed. This data is crucial for on-site energy management. Together with the data from other assets the TGP can control all energy flows behind-the-meter and control assets like the stationary battery and charging sessions (even discharging) based on specific pilot site constraints. More information on energy services and charging services are explained below.

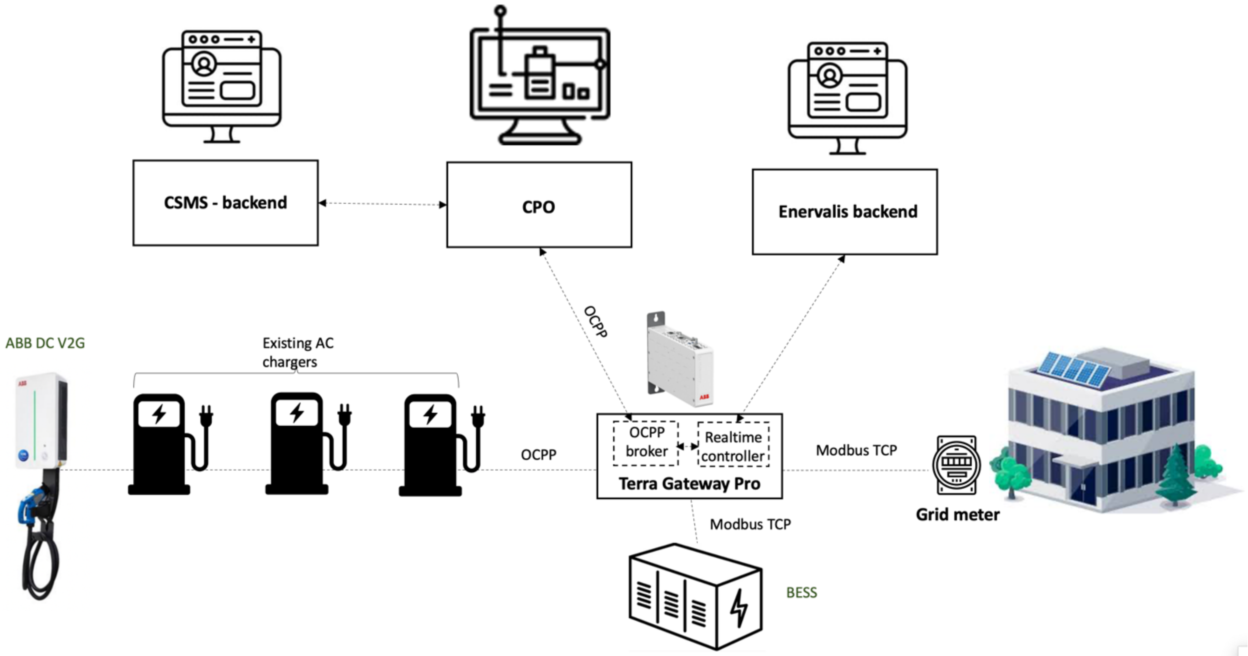


Figure 16: Architecture example with V2G and EMS capabilities

The TGP also connects to the Enervalis backend where it will also be stored. That gives the end-user the ability to configure and monitor all chargers and charging sessions and energy flows for a specific site. The data will also be stored so the historical data can be viewed later in time.

Figure 17 and Figure 18 show an example of the portal where energy management of a specific site can be monitored and controlled trough the TGP solution.

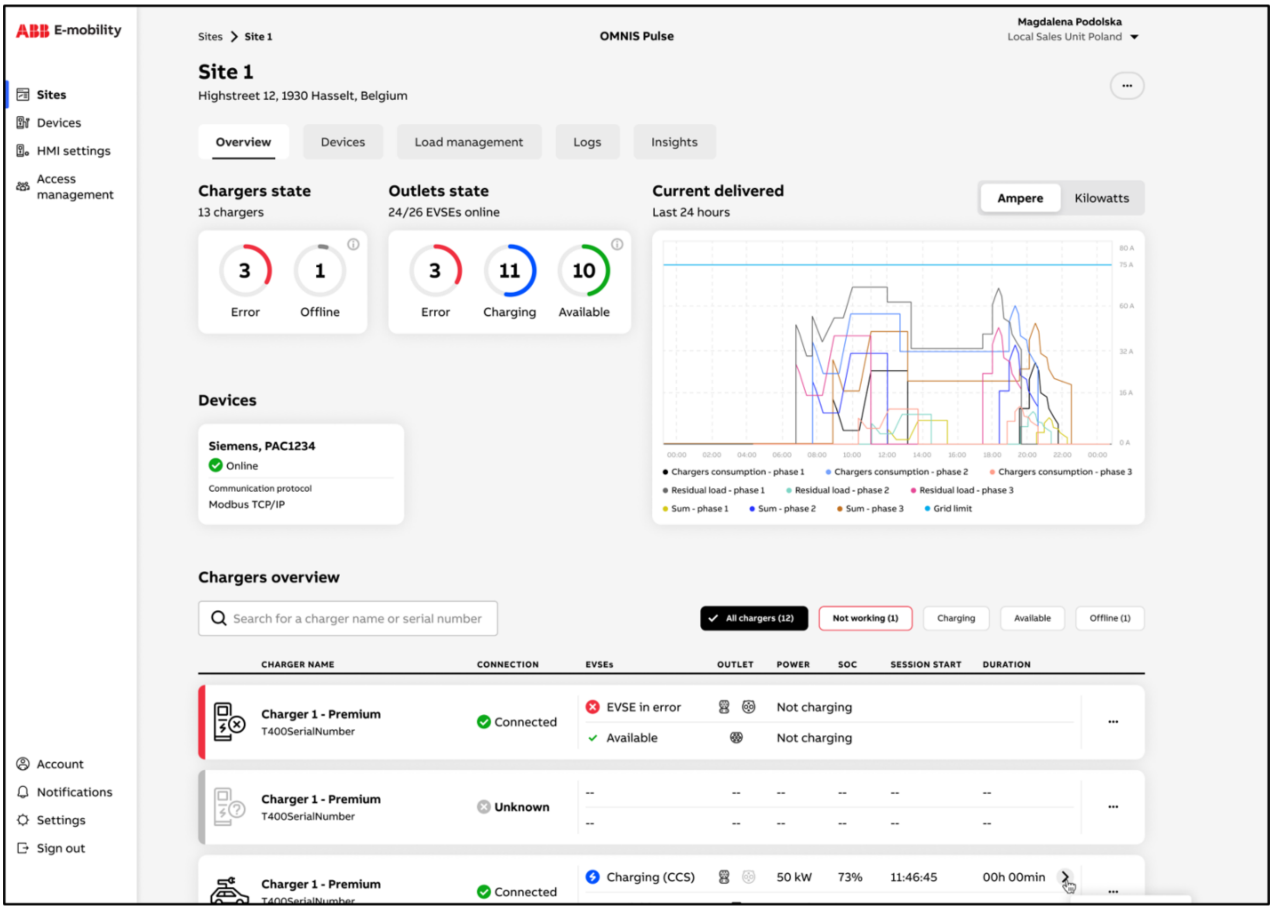


Figure 17: Site portal overview page

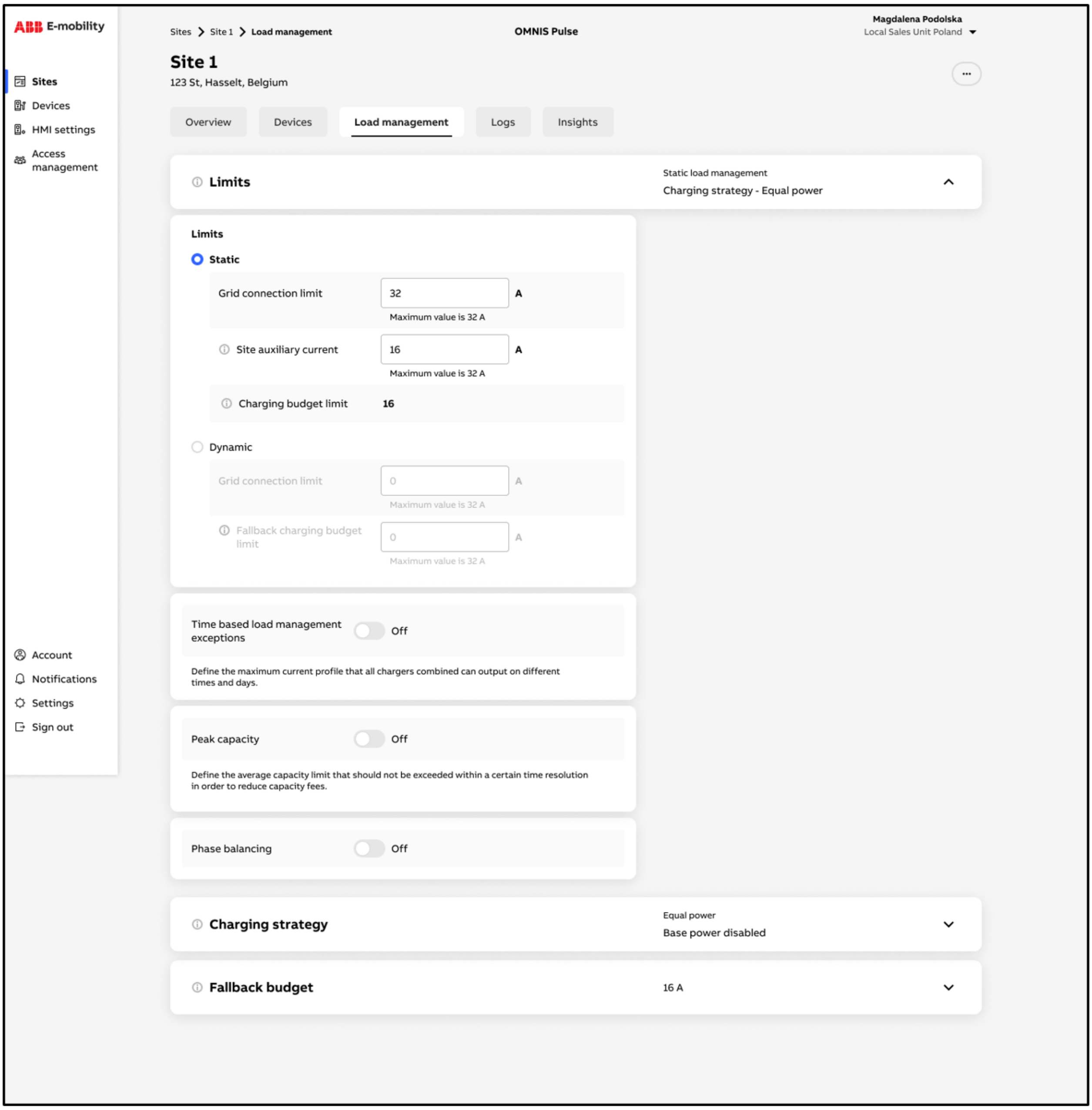


Figure 18: Site portal configuration page

9.1.2.2.1.1 Load management

The load management algorithms running on the TGP dynamically optimizes energy distribution in real-time, preventing demand surges, reducing reliance on external power sources, and minimizing operational energy costs by optimizing local consumption. This is performed by managing charging sessions in power and time. Additionally, the BESS will be used for energy peak demands or support the grid if the capacity is not large enough. This integration enhances energy reliability, supports sustainability goals, and demonstrates the viability of advanced energy solutions.

9.1.2.2.1.2 Solar charging

Solar smart charging is a system that intelligently manages the charging of electric vehicles using electricity generated from solar panels. Its purpose is to optimize energy usage, reduce costs, and maximize the use of renewable solar energy while minimizing reliance on grid power.

The system connects EV chargers to solar panel systems installed on buildings or homes and monitors the energy output of the panels in real-time. It dynamically manages when and how the EV charges, prioritizing charging when there is surplus solar power, such as during sunny periods when production exceeds household consumption. It can also balance energy distribution across appliances to avoid overloading and schedule charging during times of peak solar production.

If solar energy is insufficient, for instance at night or during cloudy weather, the system can draw power from the grid, often during off-peak times to reduce costs. In advanced setups, bi-directional chargers allow EVs to act as temporary energy storage, returning excess energy to the home or grid when needed.

9.1.2.2.1.3 V2G peak shaving

When an EV is connected to a bi-directional charger, it can store energy during times when electricity is abundant and cheap, such as during off-peak hours or when there is surplus renewable energy. Later, during peak demand, the energy stored in the EV’s battery can be fed back into the (local) grid to help reduce strain on the power system. This helps lower energy costs, stabilize the grid, reduce peak consumption and decrease the need for additional power generation from non-renewable sources.

For EV owners, V2G peak shaving provides financial benefits by allowing them to sell energy back to the grid or avoid using expensive electricity during peak times. For energy providers, it reduces the risk of blackouts and lowers the need for costly infrastructure upgrades to handle peak demand. Overall, V2G peak shaving is a win-win solution that supports a more efficient and sustainable energy system.

9.1.2.2.1.4 BESS optimization

Battery Energy Storage System (BESS) optimization can also play a crucial role in managing peak demand and storing locally produced solar energy. The system act as a buffer, during periods of peak electricity demand, when energy use is at its highest, a BESS can discharge stored energy to reduce the load on the grid. This process, known as peak shaving, helps lower electricity costs by avoiding expensive peak-time energy rates and reduces strain on the energy grid, making it more stable and reliable.

Additionally, a BESS is an excellent solution for storing locally produced solar energy. Solar panels typically generate the most energy during the middle of the day when sunlight is strongest. However, this often doesn’t align with the times of highest energy usage, such as in the morning or evening. A BESS allows excess solar energy generated during the day to be stored and used later when it’s needed most, such as at night or during cloudy periods. This makes it possible to maximize the use of renewable energy, reduce reliance on the grid, and lower electricity bills. By combining these capabilities, BESS optimization enhances energy efficiency, supports sustainability, and offers greater energy independence for homeowners and businesses.

9.1.2.2.2 VDL Valkenswaard implementation

In the first half year of the SCALE project Enervalis and VDL developed an extensive metering setup. In this way it is possible to monitoring all energy flow on site separately and in detail. All colored dots in Figure

19 represent a power meter which logs the power, current and consumed energy over time. This data is captured by an ABB DinGate device and afterwards uploaded to the Enervalis cloud.

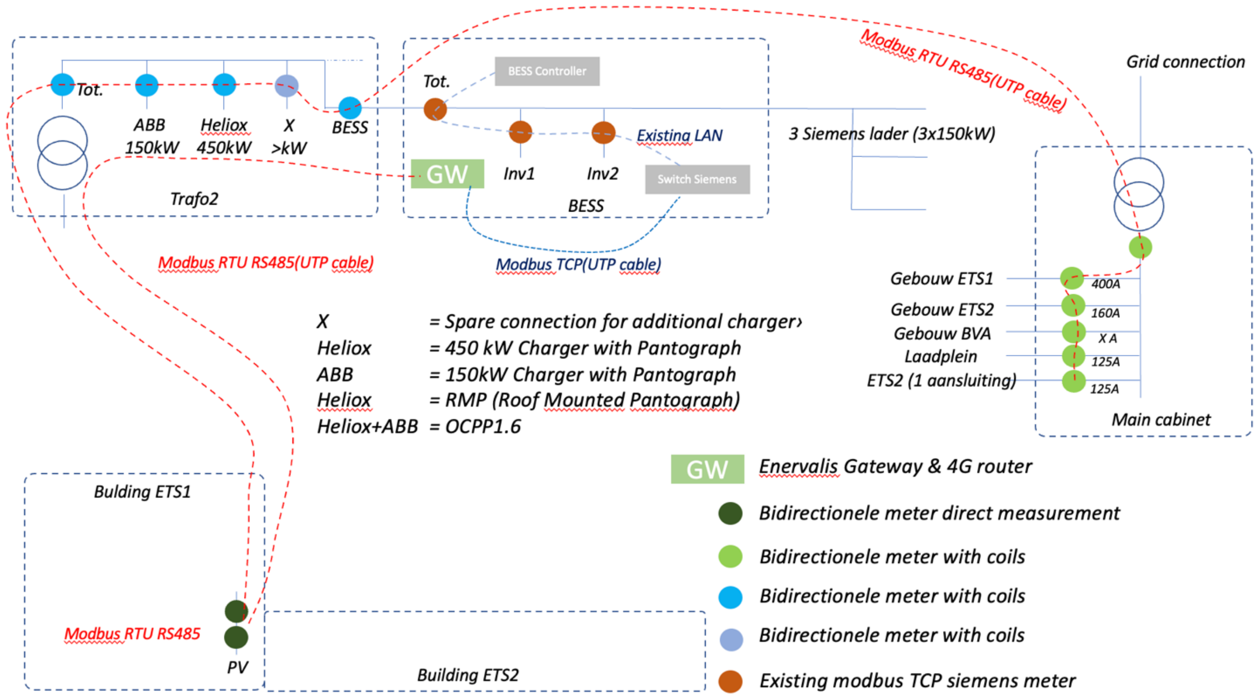


Figure 19: Metering setup VDL Valkenswaard

The measurement data is stored in the Enervalis back-end data based and can be consulted on a Grafana dashboards as shown in and Figure 20 and Figure 21. This gives a lot of insights in all the energy and the flexibility of the pilot site. Some general conclusions are that the PV system is not large enough to do multiple charging sessions, the grid connection is over dimensioned, the battery can be an added value to store the local produced energy, peak reduction can be performed by smart charging, etc…

Figure 20: Dashboard 1 datamonitoring VDL Valkenswaard

Figure 21: Dashboard 2 datamonitoring VDL Valkenswaard

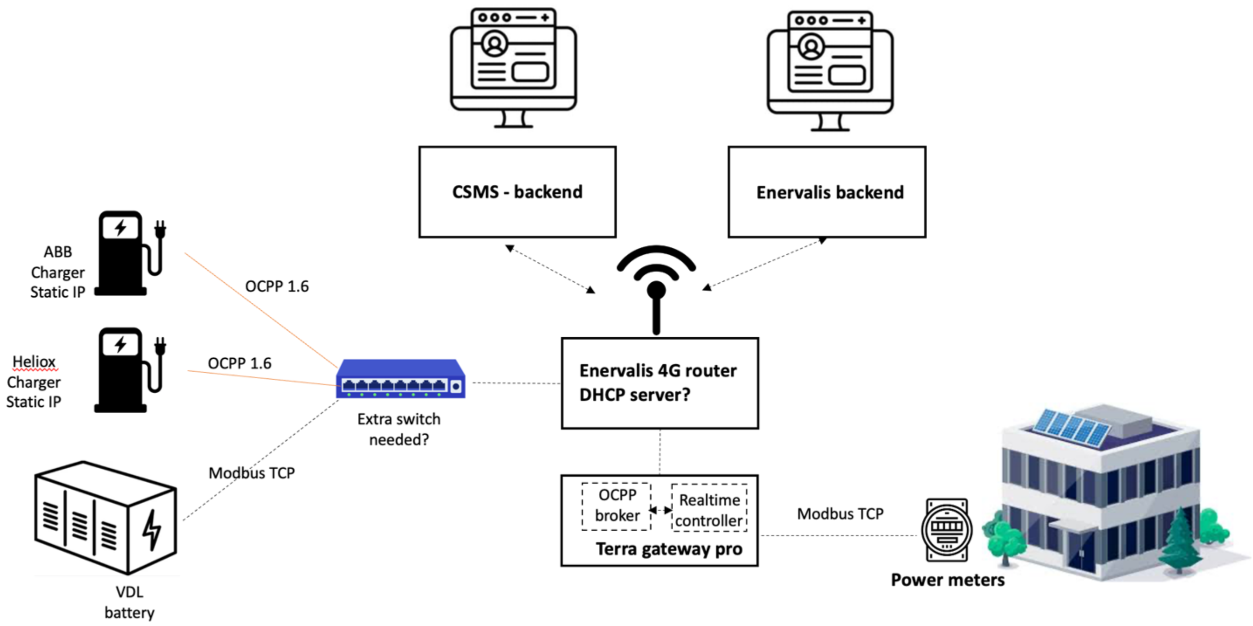


Figure 22: IT architecture for energy management at VDL Valkenswaard

During the implementation phase Enervalis had several sessions with the BESS vendor to integrate the battery to the ecosystem. During these test sessions it became clear the battery is malfunctioning and not responding to power commands. Several ways to repair the battery were investigated, but no economical was found. Also, the path of a replacement was explored without any success. Therefor VDL decided to simulate the ecosystem including a BESS to research the added value and flexibility of this important asset. This means that Enervalis is focusing on the smart charging algorithms with the two chargers only

9.1.2.2.3 Simulation approach VDL Valkenswaard

The decision was made to obtain the optimal energy flow in the network and from the grid by doing a simulation. The data is recorded by Enervalis and is being used for the EMS optimization of the charging depot. We used the components used in Valkenswaard as a reference rather than the data that was measured. For the generation of local energy, solar panels are used since they can have a positive impact on reducing the grid constraint, especially in combination with a BESS and smart charging of vehicles.

For the first use case, a charging depot, a realistic use case scenario was aimed to be modeled. Real fleet charge schedule data is used from a bus operator. The data contains the connected time to the charger and the actual SoC charged, which is used to define the availability of the vehicle and the target SoC for each charging session. The data recorded from the chargers in Valkenswaard proved to be unusable for our use cases since there is no correlation between the fleet data used from the bus operator and the charger data recorded in Valkenswaard. The fleet data is based on the real operator data, for which their own chargers were used rather than the ones in Valkenswaard. Since there is some room left in the charging schedules of the fleet, smart charging has a potential here, which is the reason why it is considered for this use case.

For the second use case, highway charging, there was no data available and therefore the charging schedule was predefined based on typical driver rest hour duration. Since the charging time for highway charging is limited, the choice was made to not include smart charging the simulations but rather rely on (high power) conventional charging.

For both use cases, the grid energy price and peak power price are considered and are based on prices of a real grid operator. Delivering energy back to the grid is not considered in these use cases. The sizing of the chargers is based on the chargers currently used in Valkenswaard, for which a maximum power of 300 kW is used for the charging depot and 450 kW for highway charging, which can be provided by the Heliox charger. For discharging, a maximum power of 45 kW is used. A BESS is used in the simulation, where the effect of varying capacities on the grid peak power and varying operational costs are explored.

To obtain a realistic solar energy generation, the data recorded in Valkenswaard proved to be useful, since the generation can be mostly seen as independent from the rest of the system (when curtailment is not taken into account). Otherwise, the recorded data could not directly be used for the model, but it can be used to gain knowledge about the optimization that can be done on the network and the direction where the optimization needs to go towards.

One of the conclusions is that the BESS helps greatly in decreasing the variable operational costs and grid peak power for both use cases. It averages the power needed from the grid by discharging when the energy needed for charging is high and charging when the energy needed for charging is low. Additionally, when the energy prices are lower, that energy can be stored in the BESS and be used later rather than the grid energy when the grid energy prices are higher.

For the charging depot, smart charging is used in the simulations to reduce grid peak power and variable operational costs and a positive effect is observed. The effect between uni-directional and bi-directional smart charging is minor. Cost wise it is not beneficial, due to multiple inverter losses and other losses that have to be overcome rather than using the energy directly from the grid. The benefits going from conventional charging to smart charging are substantial.

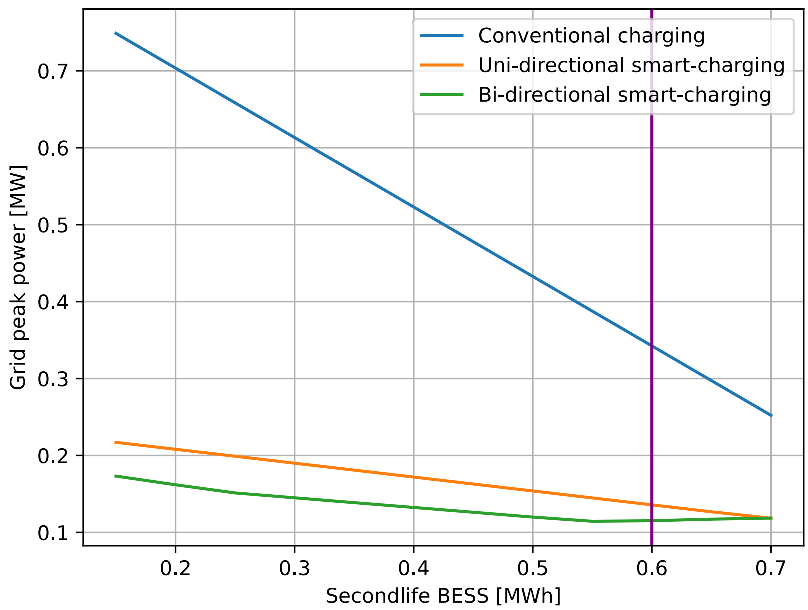


Figure 23: Grid peak power over battery capacity for different charging strategies

Finally, to reduce the grid dependency further, an extension of solar energy generation is needed. The amount of energy currently consumed in the use cases for charging the vehicles surpasses the generated energy from the solar panels greatly and therefore there will always be a dependency on the grid. As a results, it might not be realistic to fully charge a bus fleet with solar energy. Even more due to the seasonal effect on the solar energy generation and locational constraints to build the solar panels.

These conclusions are based on a limited simulation with a fixed fleet size. Different fleet sizes or different charging needs per fleet will affect the results. One of the next steps can be to considerer different fleet operators, fleet sizes and route demands to gain additional insights on the optimization.

Below a quantification of the summery is given for the simulation results, which are further explained in the WP4.2 report. A detailed list of the assumptions can be found here as well.

Solar energy generated: 43.7 MWh.

Charging energy demand for charging depot: 191.4 MWh

Peak load reduction:

- Highway charging: 36.7%.
- Charging depot: 87.2%

Variable operational costs reduction:

- Charging depot: 45.6%

9.1.3 We Drive Solar charger

At the outset of the project, the goal has been to showcase scalable AC vehicle-to-grid (V2G) operations with an anticipated volume of 500 shared EVs in and around Utrecht, using the fleet of V2G chargers operated by We Drive Solar / MyWheels. Because of two challenges, the realisation of that goal has been delayed.

Figure 24: We Drive Solar V2G charger installation

Firstly, delays in the market introduction of AC-V2G-compatible electric vehicles (EVs) and the finalization of the bidirectional ISO15118-20 protocol prevented the implementation of bidirectional charging. Although the We Drive Solar (WDS) charging stations in Utrecht are V2G-capable, the release of the ISO15118-20 standard in 2022 introduced updated security requirements that demanded significant hardware and software enhancements for chargers. As a result, the WDS chargers required an upgrade to comply with this standard. WDS is now rolling out that upgrade to all V2G chargers operated with MyWheels shared e-cars. This means that by March or April 2025, all MyWheels shared e-cars will be charged by V2G chargers.

Figure 25: Refurbishing the V2G chargers of We Drive Solar to meet the ISO15118-20 requirements

Secondly, no EVs on the market were compatible yet with the new ISO15118-20 standard, but at the moment of writing, Renault has announced their new ISO15118-20 Renault 5 and their cooperation with Utrecht[1]. In 2024, Renault and WDS have performed an extensive testing programme to ensure the V2G interoperability between the Renault 5 and the WDS chargers, with positive results. In 2025, Renault will deliver a total of 500 bidirectional Renault 5 EVs to MyWheels who will operate these including V2G charging in Utrecht. This means that in the final months of SCALE, the goals mentioned above are being met with some delay.

[1] See https://media.renaultgroup.com/renault-group-we-drive-solar-and-mywheels-join-forces-with-the-city-of-utrecht-to-launch-europes-first-v2g-enabled-car-sharing-service/?lang=eng and wide coverage in specialised as well as general media

Figure 26: Launch of the cooperation between Renault, WDS, MyWheels and Utrecht to implement Europe's first large-scale car-sharing service utilizing Vehicle-to-Grid (V2G) technology, implemented in 500 V2G Renault 5 e-cars.

9.1.4 Polestar

Polestar achieved progress in developing prototype V2G vehicles with both AC onboard charging and DC compatibility with an installation of 11 kWh onboard chargers.

- Prototype Development: Polestar 2 vehicles were rebuilt to incorporate new onboard charging components. This modification included integrating charging control components and an additional module to handle signal translation, which was necessary because the new charger components were originally designed for a different vehicle platform. As a result, custom software was developed to translate the signals effectively between the differing platforms, ensuring compatibility and functionality within the Polestar 2 vehicles.

- ISO 15118 Protocol Implementation: The prototype charger components were equipped with software implementing the ISO 15118 protocol stack. Initial testing confirmed that ISO 15118-2 AC charging was functional with the Polestar prototypes. However, the project encountered challenges with the ISO 15118-20 standard, particularly due to its immaturity, which posed obstacles for seamless V2G implementation. To adapt, the project team decided to enable V2G by extending ISO 15118-2 to support bidirectional current, allowing discharge functionality without full ISO 15118-20 compliance.

- Testing and Limitations: Due to extended delays in software development for the vehicle, testing V2G capability between the vehicle and AC charger could not be completed within the project timeline. Nonetheless, the team successfully conducted controlled AC discharging sessions in a lab environment using bench tests, demonstrating that AC discharging was technically feasible on a small scale.

This progress reflects Polestar's strategic adjustments and technical achievements despite delays, laying the groundwork for more comprehensive V2G testing and integration in future project phases.

9.1.4.1 Charging System for the Prototype Vehicles

To investigate bidirectional charging prior to production builds, the Polestar 2 production vehicles were equipped with prototype components, including a prototype Charging Electronic Control Unit (ECU), a prototype onboard charger (OBC), and a communication gateway unit (see Figure 27).

The Charging ECU manages the communication and control of charging functions, both within the vehicle system and with the Electric Vehicle Supply Equipment (EVSE).

The OBC receives AC power from the AC EVSE via the Electric Vehicle Inlet (EVI), converts AC power to DC power, and supplies energy to the high voltage battery.

To ensure compatibility of the prototype components with the electrical and electronic platform in a Polestar 2, a communication gateway unit was added to translate Controller Area Network (CAN) signals between different platforms.

It is important to note that, compared to the existing charging components in a production Polestar 2 vehicle, these prototypes are capable of bidirectional charging and are intended for newer car models.

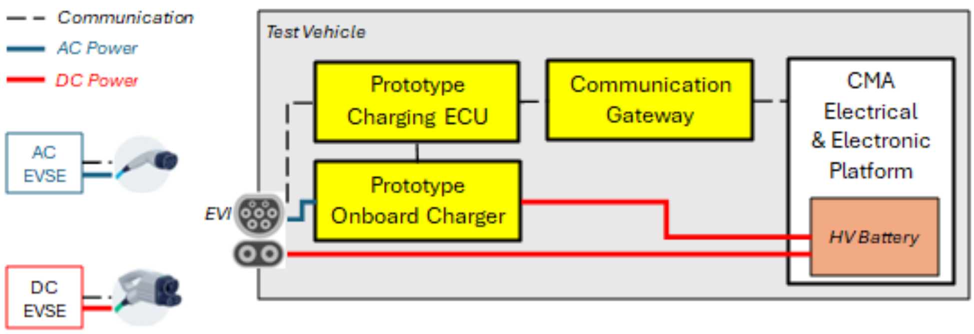


Figure 27: System architecture of the prototype vehicle

To support bidirectional charging, embedded software was developed in-house and integrated into the prototype charging ECU. The software consists of components that handles ISO 15118-2 communications and the logic surrounding the bidirectional power transfer functionality.

Furthermore, component tests were conducted in the lab before vehicle installation to ensure the correct operation of the prototype Charging ECU and OBC. These tests involved generating simulated signals using Vector CANoe and performing power transfer with a battery simulator.

9.1.4.2 Integration of Standards

The project actively integrates various industry standards, especially focusing on the ISO 15118 standards, to ensure broad compatibility and long-term viability.

- **ISO 15118-20 Standard**: Though the full implementation of ISO 15118-20 AC remains on hold pending finalized guidelines. Until then, the project utilizes ISO 15118-2 to conduct preliminary bidirectional charging tests.

- **Plug and Charge Compliance**: A significant focus of the software development team has been on integrating "Plug and Charge" functionality, a critical requirement of ISO 15118-20. This feature ensures seamless, user-friendly charging initiation without manual intervention, enhancing security and user experience. This functionality has been successfully launched on the Polestar 3 vehicles.

- **Grid Code Compliance**: Research was conducted on grid code compliance across Sweden and Europe to ensure the project's bidirectional charging technology can meet regulatory requirements across different regions. This research also supports the project's risk mitigation strategies for grid interaction and battery lifecycle management.

9.1.4.3 Prototype Charger and EV

Substantial progress has been made in both the development and testing of prototype bidirectional chargers and modified EVs.

- **Prototype Chargers**: The Ferroamp and Ctek chargers supporting both AC and DC charging were installed across various testing environments, including:
    - A **bench testing environment** to support controlled testing.
    - **Rigs** to test software-hardware integration in simulated real-world scenarios.
    - **Field testing at Polestar sites and Chalmers sites** to validate charger functionality in more dynamic conditions.
- **Software and Firmware Development**: The software development pipeline was set up to facilitate rapid iterations of firmware updates across platforms. This included:
    - Flashing new firmware onto test systems.
    - Conducting a series of software tests across different setups (bench, Vector rig, vehicle testing, and direct charger-vehicle interactions).
- **Vehicle Testing**: The modified Polestar 2 vehicles were tested for both charging and discharging functions in coordination with the prototype chargers, enabling a robust evaluation of bidirectional capabilities. Testing scenarios included:
    - **Bench testing and rig evaluations** for stability and efficiency.
    - **Real-world vehicle tests** with both AC and DC chargers, including verifying Plug and Charge functionality.
    - **Research on Battery Degradation**: A parallel research initiative focused on battery degradation, assessing the long-term effects of bidirectional charging cycles on EV batteries. This research will inform both system design improvements and lifecycle management protocols.

9.1.5 Hyundai

9.1.5.1 Road to V2G

Hyundai has a longstanding commitment to advancing Vehicle-to-Grid (V2G) technology, leveraging years of experience in smart charging (V1G). Historically, Hyundai has been involved in a pioneering V2G initiatives/pilots in Germany together with Next Kraftwerke & Hyundai Motor Group (HMG). The goal of the project was to Prequalify Hyundai Motor Group's EVs and provide secondary control. HMG provided 8x IONIQ 5 vehicles and charging stations which were located at the Hyundai Motor site in Offenbach and were grouped together in a sub-pool for the provision of secondary control reserve. This sub-pool was integrated into a Virtual Power Plant (VPP). This project lasted from 2021 to 2022.

The pilots demonstrated the potential for vehicles to act as mobile energy storage systems, providing critical insights into grid dynamics, energy transfer protocols, and user adoption challenges. Lessons learned from these early efforts helped shape the current approach for the Hyundai Motor Group scaling V2G technology.

9.1.5.2 Contributions to the SCALE Project

Hyundai has deployed 25 V2G-capable vehicles specifically for the project which is located in Utrecht, aiming to address the practical challenges of large-scale V2G implementation. This work builds on a solid foundation of smart charging (V1G) expertise, which provided valuable experience in optimizing charging schedules to manage grid load effectively.
Despite these efforts, the anticipated goal we have set is delayed due to two reasons:

1. The adaptation of the ISO 15118-20 protocol into our vehicles has been delayed. Partially this is from the fact that within the setting of the ISO 15118-20 protocol not every aspect was discussed by the controlling body in time for us to implement the last updated version of the protocol in our testing vehicles.
2. Also, we struggled with the interoperability with the chargers used for this project. We were able to discharge energy from our vehicle, through the charger to the grid. But only when doing manual and physical operation on the charger. Unfortunately, we were not able to remotely control the charger to do discharging to the grid.

9.1.5.3 Current V2G Capabilities

The deployed vehicles currently operate using the ISO 15118-2 standard, which has been instrumental in supporting the initial phases of V2G development. ISO 15118-2 offers capabilities and secure communication between the vehicle and charging infrastructure. Despite these advantages, the standard's limitations in supporting advanced energy exchange protocols have necessitated the development of models compatible with ISO 15118-20. The newer standard introduces enhanced functionalities, including dynamic energy transfer, higher power levels, and improved interoperability, all of which are crucial for the mass adoption of V2G technology.
We aim to launch a model with V2G capabilities, to go to market, within Q3 2025.

We were able to do a test at the E-laad lab with the ISO 15118-20 capable vehicle and charger to do initial lab testing. The testing results of this test are available within D2.5.

9.1.5.4 Challenges of Integration with Legacy Standards

The integration of vehicles using ISO 15118-2 with AC V2G chargers has presented several challenges.

Interoperability remains a key issue, as the older standard (ISO 15118-2) often requires additional middleware or firmware updates to ensure compatibility with newer charging systems. This complexity increases when integrating legacy systems with infrastructure designed for ISO 15118-20. These factors underscore the importance of ongoing collaboration between OEMs, charge point operators, and standardization bodies to streamline integration and certification processes.

9.1.5.5 *AC vs. DC V2G Chargers*

From a HMG perspective, the choice between AC and DC V2G chargers is largely driven by operational and regulatory considerations. While both charger types are compatible with the vehicles, each has distinct characteristics that influence deployment strategies. AC V2G chargers rely on the vehicle's onboard inverter to manage energy conversion, which places the certification burden on the OEM. This requirement increases development complexity and extends the certification timeline. Conversely, DC V2G chargers house the inverter within the charging station, simplifying the vehicle design and transferring certification responsibilities to the charger manufacturer. This makes DC chargers a more straightforward option for OEMs, reducing costs and technical risks associated with vehicle-side development.
Although due to the more extensive hardware for a DC V2G Charger vs an AC one, the costs for DC will be more expensive. It’s depending on what exactly is the business case for the V2G vehicle owner which will give the base for the choice.

9.1.5.6 *Next Steps*

To advance V2G deployment with experience of the SCALE project, we plan to:

1. Transition to ISO 15118-20 Standards:
   Finalize the development and rollout of ISO 15118-20-compliant vehicles to enable enhanced bi-directional energy flow and improved interoperability.
2. Collaborate Across Stakeholders:
   Work closely with charge point operators, energy providers, and standardization bodies to address interoperability challenges and ensure seamless integration with both AC and DC V2G infrastructure.
3. Expand Testing and Deployment:
   Scale the deployment of V2G-capable vehicles with the first V2G Capable vehicle coming to market in 2025 Q3.
4. User Engagement and Education:
   Conduct user-centric campaigns to raise awareness about the benefits of V2G, ensuring that end-users are informed and incentivized to adopt the technology.

By pursuing these steps, we will need to overcome current challenges and position V2G as a cornerstone of sustainable energy and transport systems, aligning with the broader goals of HMG towards our 2030 strategy towards an “Energy Mobilizer” and the EU’s green energy transition objectives.

9.1.6 Renault

From the beginning, Renault has been responsible for supplying two car prototypes allowing to perform V2G sessions with We Drive Solar new V2G charger. Renault has been involved on V2G technology since several years and demonstrated pioneering spirit by launching the first V2G AC car in Europe in 2024: the R5 E-TECH. The R5 E-TECH comes with compatible Renault V2G charger especially designed to be able to offer the first V2G service to customer on the European market. R5 E-TECH is also Car of The Year 2025 and has been connected successfully to Enedis Network in France with a positive injection metering. This was not directly part of the SCALE project but it helped Renault to define a robust architecture with compliant grid code.

Supporting V2G interoperability project like SCALE in the middle of a V2G vehicle launch, a V2G charger launch and a V2G service launch raised several challenges, organizationally speaking and technically speaking.

9.1.6.1 Implementation Guide

Early in the project it was decided to ease integration with any charger and to describe relevant knowledge and requirements in an implementation guide.

In this implementation guide, we outlined a comprehensive approach to deploy our system in distinct environments, each designed to meet specific testing and deployment requirements. The first environment was dedicated to performing tests without cybersecurity protection allowing thorough evaluation and validation of the messages content and sequence. The second environment was specifically testing the introduction of cybersecurity through Transport Layer Security (TLS) encryption with development certificates. The third and final environment allowed “real life condition” tests with production certificates.

The implementation guide also provided detailed Dos and Don’ts to operate V2G sessions with Renault V2G prototype.

In addition, general knowledge on grid code compliance was included in the implementation guide, and especially grid code split in Renault implementation.

Experience showed that the implementation guide content was clear enough for most of the technical development to be done on EVSE side. Few difficulties around cycling zone rules required further explanations and additions in the implementation guide, mainly about authorized discharge and charge area. Some additions were made during the project life to enrich the details on the way to send mobility needs and manage the PKI for instance.

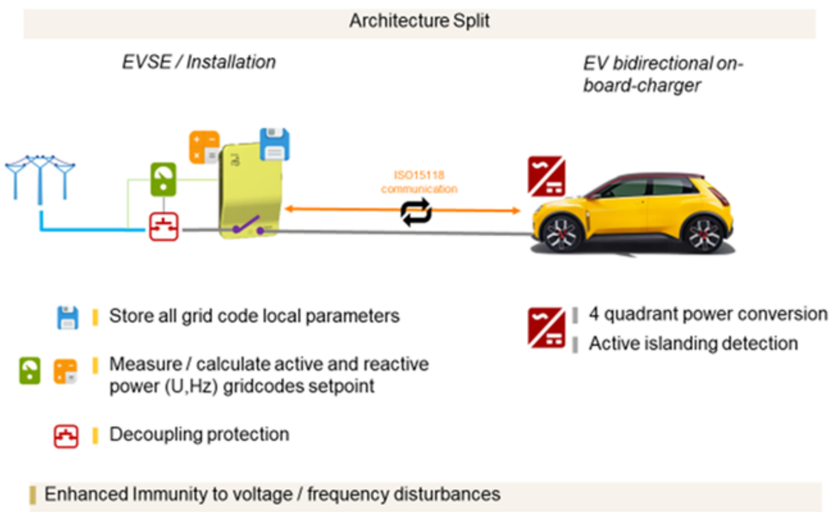


Figure 27: The implementation guide is part of Renault deliverables for SCALE project

9.1.6.2 V2G prototypes

Initially planned before the launch of the Renault R5 E-TECH, production and delivery of V2G prototypes have been frequently on the critical path. To avoid potential priority issue with R5 project development, decision was made early 2024 to use another Renault EV for car prototype delivery and to swap the onboard charger as well as some ECU with the ones used on R5. After the planned hardware changes, several software updates and some specific actions to enable the V2G feature, one functional V2G prototype was eventually built with same V2G performance as R5 prototypes. Decision was quite relevant since R5 prototypes were at that time still running extensive tests before industrialization and were logically precious as gold.

To ensure some experiments in public environment, plan was made to deliver two R5 V2G prototypes with licence plate later in the project. Unfortunately, the full process leading to the licence plate obtainment took far more time than expected and R5 V2G prototypes available have not yet access to public infrastructure..

9.1.6.3 ISO 15118-20 communication between V2G charger and V2G vehicle

Availability of the first V2G EV prototype for SCALE project unlocked the possibility to run an integration session, which took place in Renault lab with local support from We Drive Solar team. During this first test session, a V2G session was initiated, and first ISO 15118-20 messages were exchanged. Despite shortcuts used to avoid cybersecurity protection on V2G EV prototype and manual order on charger side, demonstration was made that integration was technically possible.

The integration strategy to build a prototype, to test it with existing Renault V2G charger and then to integrate it with We Drive Solar charger significantly limited the risk of major issues during the integration session performed with We Drive Solar team. Before the integration session took place, 6 use cases were tested with V2G EV prototype and Renault V2G charger before being performed with WeDriveSolar charger.

To have efficient investigation on vehicle side, Trialog also attended the integration session and brought a sniffer to capture all message exchanged.

Use Case	Description	Renault V2G charger	WeDriveSolar charger	Results
1	Activation of the service and creation of a Program	x		
2	V2G session validated with the Powerbox Mobilize	x		
3	Communication session opened with WDS charger (15118-20) (Mobility needs set inside the vehicle)	x	x	
4	Opening of a Charge Loop	x	x	
5	V1G charge (P>0W) - 15118-20	x	x	
6	V2G Charge (P<0W) - 15118-20	x	x	

List of use cases tested during first integration session

Inclusion of ISO15118-20 cybersecurity requirements constituted the next challenging step. Overcoming some technical difficulties in communication protocols, cybersecurity was successfully tested. Following this success, two V2G EV prototypes have been built, and one was delivered to We Drive Solar team to ease development. Despite availability of R5 prototypes in October 2024, current delivery of both R5 prototypes has unfortunately been delayed due to unexpected administrative issues. Only one R5 prototype was shipped to ensure test by We Drive Solar in final conditions. Tests in Elaad Test Lab has also been delayed due to limited number of prototype available.

9.1.6.4 Public Key Infrastructure (PKI)

ISO15118-20 implies specific cybersecurity protection. Indeed, communication between a V2G EV and a V2G charger requires certificate exchanges and mutual authentication. A detailed review was performed to analyse all possible options for the SCALE project. To keep planning realistic in project timeframe, decision was made to use Renault PKI for WeDriveSolar V2G charger. For a better interoperability in the future, a dedicated company should hold the certificate generation to give the warranty that all V2G EV and V2G charger are compatible with each other. Interoperability remains a key issue while waiting for this authority empowered to generate certificates allowing mutual authentication. This limitation underscores the importance of ongoing collaboration between V2G EVSE suppliers and V2G EV suppliers to ensure a future interoperable V2G.

9.1.6.5 Mobility needs

Beyond V2G EV prototype build and ISO15118-20 communication challenges, purpose of SCALE is also to demonstrate possibility to use car sharing and V2G in the city of Utrecht. To ensure a complete car sharing process with mobility needs change depending on rental request, an investigation was made to provide simple command mechanism. Consequently, Renault is developing specific commands inside fleet management tool to allow an external company with allowed credentials to be able to set the mobility needs i.e. SoC target and departure time. This development and associated integration tests are still ongoing and should be finalized in the coming weeks.

9.1.6.6 Next steps

Remaining activities are:

- Delivery of final R5 V2G prototype with license plate.
- API integration to send mobility needs and activate/deactivate de V2G service
- Ensure technical support during End to End integration tests by WeDriveSolar

9.1.7 Trialog protocol stacks

Trialog developed software stacks implementing communication protocols that can be integrated into AC and DC charging stations to accelerate and simplify charging station manufacturer development phase. Two stacks covered the different interfaces of the charging station:

- Communication with the vehicle (YaCCS).
- Communication with an OCPP backend (QOCPP-CS).

YaCCS solution supports CHAdeMO, DIN 70121 and ISO 15118-2 protocols. It has been extended to support ISO 151118-20 protocol within the project.

QOCPP-CS solution supports OCPP 1.6 and OCPP 2.0.1. It has been extended to implement some messages of the draft version of OCPP 2.1 to control V2G with use cases Q04, K19, DER01 within the project.

These two solutions are currently used by several actors around the world, mainly for V1G. Within the SCALE project, they have been both deployed into two AC bidirectional stations and will be deployed into a DC bidirectional station by the end of the project at ElaadNL facilities with the objective to test V2G use cases. Moreover, the QOCPP-CS stack is deployed into We Drive Solar chargers that will be demonstrated in Utrecht.

The development of these 2 solutions will continue to consider feedback from testing sessions organised during the project but also after to enhance interoperability. Support of OCPP 2.1 will also be extended in the future following the finalised version expected in 2025 to add new use cases to meet our customer needs.

9.1.8 Trialog EVI solution

Since 2019, Trialog, with its partner Watt&Well, is proposing the EVI solution to accelerate the development of DC charging stations. The EVI solution is an ISO 15118 EVSE Controller that can be used by charging station manufacturers into their station. It takes care of the PLC communication with the vehicle during the recharge process and simplifies the integration of power modules inside the stations. It supports CHAdeMO, DIN 70121, ISO 15118-2 and implements IEC 61851-23. Watt&Well provides the hardware and software to control the power units of the EVI solution, and Trialog provides the communication software based on Trialog's software stacks (see previous chapter).

Figure 28: EVI Solution

Within SCALE, Trialog integrated its ISO 15118-20 DC V2G stack and its OCPP 1.6 stack into the EVI solution. Within a test bench, the EVI solution was able to demonstrate DC V2G charge and discharge (up to 22kW) with the EV emulator from Trialog (EV ComboCS). To properly control the charge and discharge of the vehicle, the Trialog's OCPP 2.0.1 stack will also be integrated into the EVI solution in addition to the OCPP 1.6 version by the end of the project. If possible, some OCPP 2.1 messages (draft version) will be implemented and tested using the Trialog's test CSMS and will be able to properly demonstrate how to control bidirectional charge for a charging station operator.

This solution is already used by several actors around the world, mainly for V1G. One of the EVI's users is currently performing DC V2G charge with the EVI solution and another EVCC implementation. Within SCALE, this solution will be deployed into a DC station by the end of the project at ElaadNL facilities with the objective of testing V2G charge and thus maturing the solution.

10 Protocols

Overview/Summary

As the transition to electric mobility accelerates, the integration of smart charging and V2G technologies has become critical for ensuring the efficiency, stability, and sustainability of energy systems across Europe. The SCALE project focuses on enabling this transition by developing and implementing innovative charging solutions that are interoperable, scalable, and future-proof. A key component of this integration lies in the robust communication protocols that facilitate seamless data exchange and operational coordination between various stakeholders in the energy and mobility domains.

This chapter delves into the technical foundation of the SCALE project's smart charging and V2G infrastructure, highlighting the communication protocols that ensure interoperability between electric vehicles (EVs), charging stations, energy management systems, and grid operators. The protocols and gaps discussed in D2.2 and D2.3 include the latest advancements in ISO 15118-20 for secure and dynamic vehicle-to-charger communication, OCPP for managing charging infrastructure, OpenADR for grid flexibility, and Equigy's Crowd Balancing Platform for balancing grid demands with distributed energy resources.

By standardizing and enhancing these protocols, the SCALE project not only supports the integration of renewable energy sources but also facilitates active participation of EVs in grid balancing and demand response markets. This chapter will provide a comprehensive overview of these protocols, their role in the SCALE ecosystem, and their contributions to advancing Europe's energy transition.

ISO15118-20

ISO 15118-20 was published to improve charge methods that reduce efforts and agonies of the charging operation and extend functions for the electric vehicles to be utilized as distributed energy resources, which enable smoothing of the electricity load of the supply network for higher energy efficiency and also provide power back to the grid and give information services for the user with higher added value and new convenience.

10.1.1 ABB Implementation of ISO15118-20

ABB Terra Nova 11 prototype chargers are one of the first charger products in the ABB product category that operate in three different standards for communication between the vehicle and charge station including the most common DIN 70121, ISO15118-2 and ISO15118-20 which makes it one of the most robust charging stations that could be possibly interoperable with most of electric vehicles that are currently available in the European market and also future-proof for newer EV models that will be launched in the future with ISO15118-20 including bi-directional smart charging.

10.1.2 ISO15118-20 DC Charge Session Message Sequence Diagram

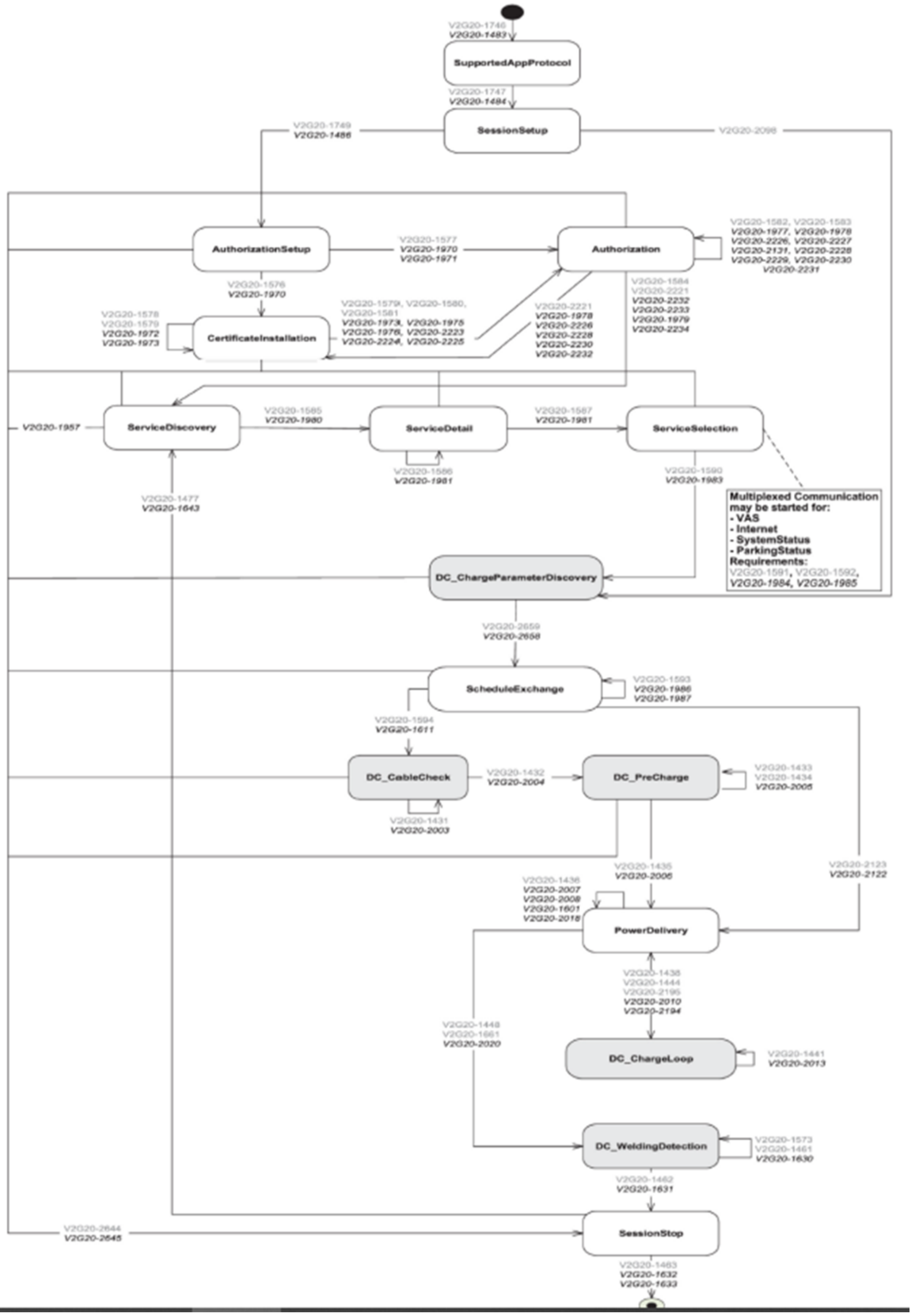


Figure 29: ISO15118-20 DC Charge Session Message Sequence Diagram

10.1.3 New Message Type Cre ated ISO15118-20

ISO15118-20 DC BPT	
SupportedAppProtocolReq	SupportedAppProtocolRes
SessionSetupReq	SessionSetupRes
AuthorizationSetupReq	AuthorizationSetupRes
AuthorizationReq	AuthorizationRes
CertificateInstallationReq	CertificateInstallationRes
ServiceDiscoveryReq	ServiceDiscoveryRes
ServiceDetailReq	ServiceDetailRes
ServiceSelectionReq	ServiceSelectionRes
DC_ChargeParameterDiscoveryReq	DC_ChargeParameterDiscoveryRes
ScheduleExchangeReq	ScheduleExchangeRes
DC_CableCheckReq	DC_CableCheckRes
DC_WeldingDetectionReq	DC_WeldingDetectionRes
PowerDeliveryReq	PowerDeliveryRes
DC_ChargeLoopReq	DC_ChargeLoopRes
DC_WeldingDetectionReq	DC_WeldingDetectionRes
SessionStopReq	SessionStopRes

Figure 30: ISO15118-20 message types

Message types marked with yellow background are developed/adjusted in ABB Terra Nova 11 charger software according to ISO15118-20 standard as they have major changes from ISO15118-2. In our current implementation for bidirectional power transfer (BPT) only dynamic discharge mode is supported, where in both ChargeParameterDiscoveryReq & Res messages, BPT_DC_CPDReqEnergyTransferMode element is added for EVCC or EVSE for initiating the target setting process for DC bidirectional charging while in DC_ChargeLoopReq and Res messages, BPT_Dynamic_DC_CLReqControlMode is used for offering and setting parameters for dynamic control mode BPT.

OCPP

Open Charge Point Protocol (OCPP) versions 2.0.1 and 2.1 play a significant role in enabling smart charging and bidirectional charging capabilities for electric vehicles (EVs). OCPP is an open standard that facilitates communication between charging stations and central management systems, making it a widely adopted protocol for interoperability and advanced EV charging functionalities.

OCPP 2.0.1 provides the foundation for bidirectional charging. It introduces functionalities like enhanced device management, finer control over charging profiles, and improved security measures. Crucially, OCPP2.1 natively supports Vehicle-to-Grid (V2G) capabilities, enabling bidirectional charging where electric vehicles can discharge stored energy back to the grid or a building's energy system. This feature allows for grid stabilization, renewable energy storage optimization, and cost savings for users, as EVs can act as mobile energy storage units.

By providing these capabilities OCPP2.1 empowers charging operators and energy providers to optimize EV charging infrastructure, enhance grid stability, and facilitate the adoption of sustainable energy solutions. This evolution highlights the critical role of communication protocols in advancing smart and flexible EV charging systems for a greener energy future.

In OCPP version 2.1, various messages support smart charging and bidirectional charging capabilities. Here are some examples of messages involved in these functionalities:

Examples of Smart Charging Messages:

1. `SetChargingProfile`:
    a. This message is used by the central management system to send a charging profile to a charging station. The charging profile defines maximum current limits, schedules, and other parameters for smart charging. It supports optimizing energy distribution and prevents overloading the grid.
    b. **Example Use Case**: An EV can be charged during off-peak hours at a lower cost, with the profile ensuring charging occurs when energy prices are lowest.
2. `GetChargingProfiles`:
    a. This message allows a central system to request information about the current charging profiles set on a charging station. This helps manage and monitor active charging strategies.
    b. **Example Use Case**: An operator checks which charging profiles are currently active for a specific group of EVs to optimize energy balance.

Examples of Bidirectional Charging (Vehicle-to-Grid - V2G) Messages:

1. `SetVariableMonitoring`:
    a. This message allows parameters on a charging station, such as current or voltage, to be monitored. This is useful for bidirectional charging as it helps monitor and control energy transfer between the vehicle and the grid.
    b. **Example Use Case**: Monitoring the power supply to ensure that an EV battery is discharging energy to the grid in a controlled manner.

These messages demonstrate how OCPP 2.1 offers an extensive set of communication capabilities to support both smart charging strategies and bidirectional energy transfers, which is essential for the future integration of electric vehicles into the energy grid.

The new We Drive Solar chargers operate with OCPP 2.0.1.

OCPI

The Open Charge Point Interface (OCPI) is a key protocol used to facilitate smooth communication between various players in the EV charging ecosystem. It enables effective data exchange and supports advanced features like smart charging and V2G operations.

OCPI connects CPOs and MSPs, along with other service providers, to manage dynamic energy pricing, personalized charging profiles, and energy management. The latest version, OCPI 3.0, introduces a Power Regulation Module that enhances smart charging and V2G capabilities. This builds on earlier versions, such as OCPI 2.2.1, by providing tools for energy regulation and improved interaction between systems.

OCPI 3.0 is used to support smart charging by dynamically adjusting energy flow based on prices, grid demand, and user preferences. It also enables bidirectional energy transfer, allowing EVs to supply energy back to the grid as distributed energy resources.

The inclusion of OCPI provides several benefits. It integrates systems like ISO15118-20 enabled vehicles, OCPP operated chargers, and service providers, ensuring consistent communication across the network to EMSPs. It supports smart charging use cases by enabling user-specific energy management and demand-response features to reduce grid strain during peak times. The protocol's modular design ensures scalability, allowing it to adapt as EV technologies evolve, and its backward compatibility with older versions, such as OCPI 2.2.1, helps stakeholders transition smoothly to newer functionalities.

However, challenges remain. Aligning OCPI with the latest versions of other standards, such as ISO15118-20 and OCPP, requires continuous updates. Additionally, some stakeholders still use older versions like OCPI 2.1.1, which lack support for smart charging. The SCALE project is addressing these issues by exploring compatibility solutions and proposing improvements.

As part of the project, SCALE has analyzed its smart charging requirements and identified how OCPI 3.0 addresses them. A whitepaper is being developed to explain how OCPI can be used for large-scale V2G and smart charging. The project is also providing recommendations for future enhancements to OCPI to meet emerging energy needs.

Through its application OCPI contributes to making smart charging and V2G systems more efficient, scalable, and user-friendly, supporting a sustainable and interconnected future for electric vehicles.

aFRR (CBP)

Equigy is a joint venture of 6 European TSOs which has been developing the Crowd Balancing Platform (CBP) since 2020 to facilitate the integration of smaller distributed flexibility assets, such as home batteries and electric vehicles (EVs), into electricity balancing markets. By creating a trusted data exchange, Equigy enables aggregators to support grid stability and facilitate the energy transition.

Equigy plays a critical role in transforming how energy systems operate by enabling decentralized energy resources (DERs) to participate in balancing markets. Traditionally, grid balancing relied heavily on large, centralized power plants, such as gas and coal plants. These plants increase or decrease their output to maintain the balance between electricity supply and demand. However, Equigy's innovative crowd balancing platform (CBP) is paving the way for smaller, distributed flexibility assets to take over this role, contributing to a cleaner, more efficient, and cost-effective energy system.

10.1.4 Key Capabilities of the Equigy Platform

- Communication Between Aggregators and TSOs: Equigy facilitates seamless interaction between aggregators and TSO's through key processes such as registration and prequalification of resources, capacity and energy bidding, activation of flexibility services, real-time monitoring, offline data transmission, settlement, and visualization of data for TSOs.
- Key Capabilities Used in the SCALE Project:
    - In the context of the SCALE project, Equigy's platform will receive the baseline and aggregate data from Enervalis at 4 second interval. These datasets are meant to be visualized and compared in Grafana.

- Two datasets were analyzed in the context of aFRR activation: one containing data from individual devices, transmitted at a 15-minute frequency, and another containing pool-level data, transmitted at a 4-second frequency. Since the Dutch TSO operates exclusively with pool-level data and the total values in both datasets are equivalent, Enervalis and Equigy opted to work with the 4-second data.

- Equigy will visualize the 4-second data provided by Enervalis using Grafana. However, endpoints and corresponding pipelines have also been established for the 15-minute data. This ensures that, in a real-life scenario, the 15-minute data can be utilized alongside the 4-second data for activation monitoring and data validation.

10.1.5 aFRR minimal viable product with EV chargers

Enervalis, acting as the Flexibility Service Provider (FSP) in the project, will also send mock aFRR activation signal. The test of the aFRR activation will involve sending aFRR signals to pools of chargers during high-flexibility periods, validating the readiness of flexibility assets to respond to activation signals and ensuring that the reaction time and ramp-up rate matches TSO expectations. At the time of writing end-to end test is prepared from an incoming aFRR activation trigger coming in going through the full software chain until the charge points reacting to the aFRR setpoint by reducing the charging power or delivering energy back into the grid as long as needed. The timing of this setpoint is coming from the CBP platform if the setup is operational, for testing purposes this activation will be simulated to add extra flexibility.

Figure 31 shows a high level aFRR process overview for a public charger infrastructure equal to the pilot site of Utrecht of We Drive Solar, which provides the physical charging infrastructure for electric vehicles. These chargers collect real-time charging data as they operate. The Charging Station Management System (CSMS) from Last Mile Solutions (LMS) manages the chargers and aggregates data from multiple charging stations. LMS collects information about each charging session, including power usage is sends an update every 15 minutes for each charger. These updates are not synchronized, which means every charger sends their update randomly somewhere in a 15 minute interval, all updates are not send at once every 15 minutes.

Enervalis, as the Smart Charging Service Provider, plays a crucial role in the system. It acts as the interface between LMS and the market, represented by Equigy. Enervalis offers flexibility services by controlling a pool of chargers and uses historical data along with predictive algorithms to calculate the expected flexibility of the charging network. Based on these calculations, it forecasts aFRR bids and submits them accordingly. Additionally, Enervalis provides measurement data and setpoints to ensure optimal energy dispatch.

Equigy serves as the Crowd Balancing Platform, connecting flexibility providers like Enervalis to the energy market. It processes flexibility bids from Enervalis and ensures they align with grid demands. When the Transmission System Operator (TSO), TenneT, detects frequency deviations on the grid, it sends balancing requests to Equigy. In response, Equigy communicates these activation requests to Enervalis, which then adjusts the charger setpoints through LMS.

In this process, LMS ensures real-time data collection and charger control, while Enervalis forecasts flexibility, optimizes setpoints, and interfaces with Equigy. Equigy aggregates flexibility bids and relays activation requests, and TenneT determines the need for frequency regulation. This setup enables electric vehicle chargers to participate in the ancillary service market, providing valuable grid balancing services while optimizing charging operations.

For validation of an aFRR activation, the TSO requires 4 second data. This means that every charger needs to upload their measurements at least every 4 seconds. Since Enervalis only receives an update of each charger every 15 minutes Enervalis enhances this data set and converting it to 4 second date on pool level using some algorithms, this means this data is less accurate and approximated as closely as possible. In the ideal situation, a setpoint should be send every 4 seconds for each charger by LMS but this was not feasible to get this into practice. Figure 32 shows a Grafana graph of the aggregated pool data, this is sent to Equigy for validation of the aFRR delivery and used by Enervalis to compute the flexibility.

aFRR requires at least a flexibility of 1MW, to reach this amount a lot of active charging sessions are needed. This means the data to be handled will be extensive if each charger should upload the data at 4 second basis. Most of the CPO's use mobile data to communicate with the charger infrastructure, which is limited and expensive. To handle these amounts of data Enervalis and Equigy recommend implementing a delta monitoring communication strategy. The charger will only upload the measurements if there are defined changes or fluctuations in the measurements. The threshold level can be determined based on the needed accuracy for data validation. If no updates are sent the back-end system will assume the last measurement is still valid and will build-up the complete dataset. This way, the communication frequency and data transfer is reduced significantly with a little effort from the back-end system.

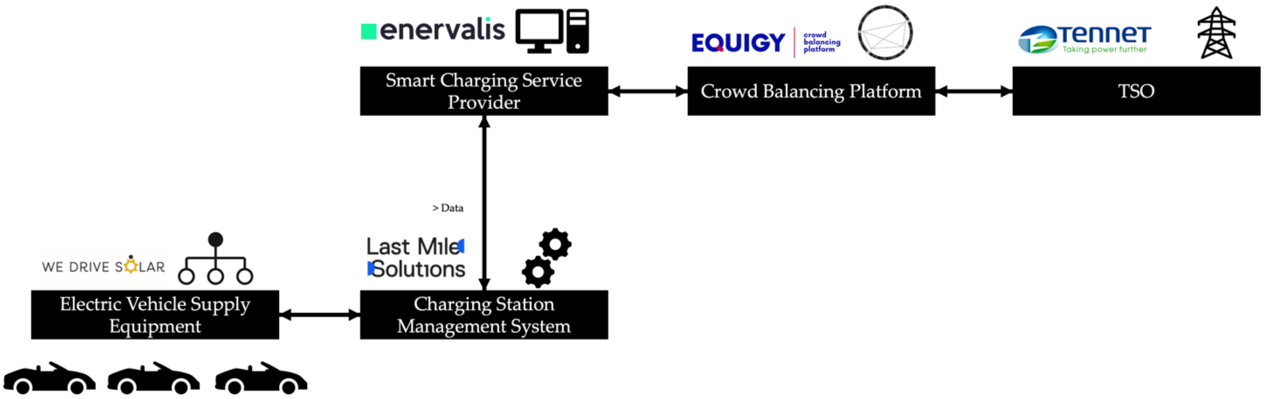


Figure 31: Schematic E2E system overview

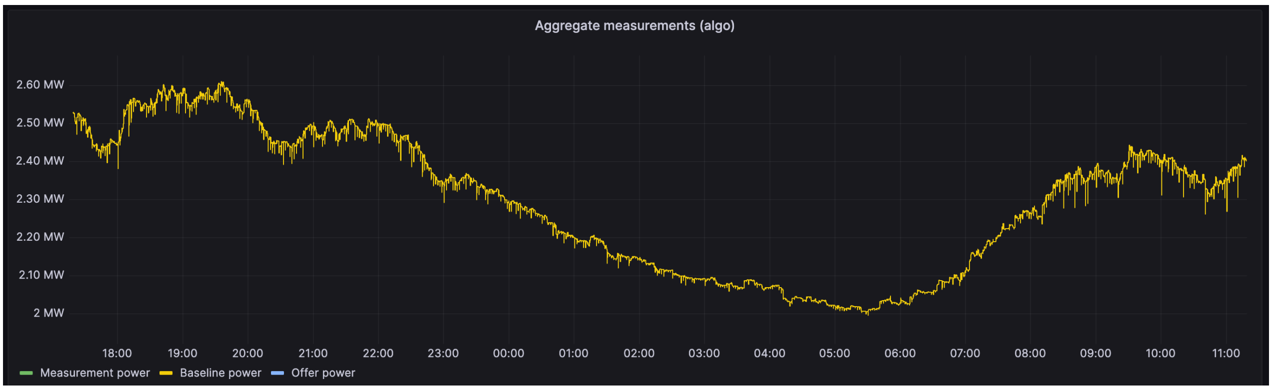


Figure 32: Aggregated pool measurements of We Drive Solar chargers in Grafana

Value-add of Equigy's CBP for aFRR activation from the perspective of an electric car fleet aggregator:

- **Simplified connectivity compared to SCADA protocols:** the CBP eliminates the complexities associated with traditional SCADA protocols by providing a modern and streamlined connection framework. This simplification reduces the technical overhead for electric car fleet aggregators, enabling them to focus on their core operations rather than managing complex system integrations.
- **Cost reduction through easy connection logistics:** The straightforward connection process to the CBP minimizes setup costs and resource requirements. Aggregators no longer need to invest in expensive proprietary solutions or extensive technical adaptations, making it more affordable to participate in aFRR markets.
- **Guidance through complex registration processes:** Equigy supports aggregators throughout the often-daunting prequalification and registration process with TSOs. This assistance ensures compliance with regulatory requirements while reducing the administrative burden on aggregators, allowing them to onboard with greater confidence and efficiency.
- **Fast Onboarding, connection ready in weeks:** With Equigy's CBP, the onboarding process is significantly faster than traditional systems, taking only a few weeks from start to finish. This speed empowers electric car fleet aggregators to quickly enter the aFRR market, monetize their flexibility resources, and begin generating revenue sooner.

Equigy's integration with Enervalis as part of the SCALE project showcases its commitment to enabling a sustainable energy transition. By connecting distributed flexibility assets to energy systems, Equigy supports the efficient utilization of renewables, grid balancing, and the evolution of European electricity markets. Enervalis facilitates the middle in the man solution which means collecting the measurements of the We Drive solar chargers and send the measurements to the CBP for validation, forecasting the available flexibility in time, translate this in a bid which will be placed on the CBP platform. If a setpoint is received from the CBP the Enervalis back-end translate this to individual charger setpoints and send them individually to each charger.

OpenADR

Open Automated Demand Response (OpenADR) is a standardized communication protocol that facilitates seamless integration between energy providers, grid operators, and end-users. This protocol plays a critical role in enabling smart charging and bidirectional charging, two essential components of modern energy ecosystems. OpenADR supports smart charging by providing a reliable framework for real-time communication between charging stations and energy management systems.

- **Demand Response Signals**: OpenADR enables utilities to send demand response (DR) signals to charging stations, adjusting charging schedules based on grid requirements. For instance, during peak load periods, charging can be delayed or reduced to prevent grid overload, while off-peak hours can be utilized for faster charging at lower costs.
- **Energy Price Integration**: By incorporating dynamic pricing information, OpenADR allows EV owners to charge their vehicles when electricity rates are lowest. This not only reduces costs for consumers but also encourages load balancing across the grid.
- **Load Forecasting and Optimization**: OpenADR facilitates the integration of predictive algorithms that forecast energy demand and adjust charging schedules accordingly. This ensures efficient utilization of renewable energy, such as solar or wind power, when available.

OpenADR supports bidirectional charging by enabling the necessary communication between EVs, charging infrastructure, and grid operators.

- **Dynamic Energy Flow Control**: OpenADR's real-time communication capabilities allow grid operators to request energy discharge from EVs during high-demand periods. This helps stabilize the grid and reduces reliance on fossil fuel-based backup systems.
- **Grid Resilience**: During outages or emergencies, OpenADR can coordinate energy discharge from EVs to critical infrastructure, enhancing grid resilience and reliability.
- **Revenue Opportunities**: OpenADR enables utilities to offer incentives to EV owners for participating in V2G programs. By selling stored energy back to the grid during peak periods, EV owners can offset their charging costs, making bidirectional charging economically attractive.

One of the key advantages of OpenADR is its open, vendor-neutral design, which ensures interoperability across diverse systems and devices. This is particularly important in smart charging and bidirectional charging ecosystems, where seamless communication between multiple stakeholders is essential. OpenADR's scalability also supports the increasing penetration of EVs, ensuring that energy systems remain efficient and reliable as demand grows. On top of the technical tool that OpenADR is, there is still a need for agreement on which signals to use. This can be agreed between two parties directly but preferably this is agreed upon within a governing structure. This could be local, national or international.

OpenADR already has 3 versions. Version 3.0 was released in 2023 by the OpenADR Alliance and represents a modern approach to demand response. It utilizes REST API principles instead of the SOAP/XML framework used in earlier versions, simplifying the integration.

OpenADR 3.0 provides several advantages that make it a valuable tool for modern energy systems. It is highly compatible with a wide range of energy resources, grid technologies, and demand response programs, ensuring it can adapt to new developments in the energy sector. Security has been significantly improved with stronger encryption and authentication measures to protect data and infrastructure. Its design, based on REST APIs, simplifies integration and configuration, making it easier for new participants to adopt. OpenADR 3.0 is also more scalable and performs reliably even under heavy loads and diverse conditions.

The platform is designed to be future-ready, supporting innovations like microgrids, energy storage, and electric vehicle charging, which ensures its long-term relevance. By improving demand-response coordination, it helps create more stable grid operations and reduces costs. Overall, it delivers a better user experience with streamlined processes and tools, making it easier for organizations and individuals to benefit from demand response programs.

The benefits of OpenADR 3.0 include future-proofing the energy landscape for innovations like microgrids, energy storage, and EV charging. It lowers barriers to market entry, enabling broader participation while enhancing demand-response coordination for stable grid operations and cost efficiencies. Additionally, the improved end-user experience contributes to its potential for widespread adoption.

11 Software

11.1 Behind the meter and in front of the meter optimization

The figure below shows the boundary of in front and behind the meter. In general, everything related to the energy grid is related to in front-of-the meter. Everything what on a local site can be related to behind-the-meter.

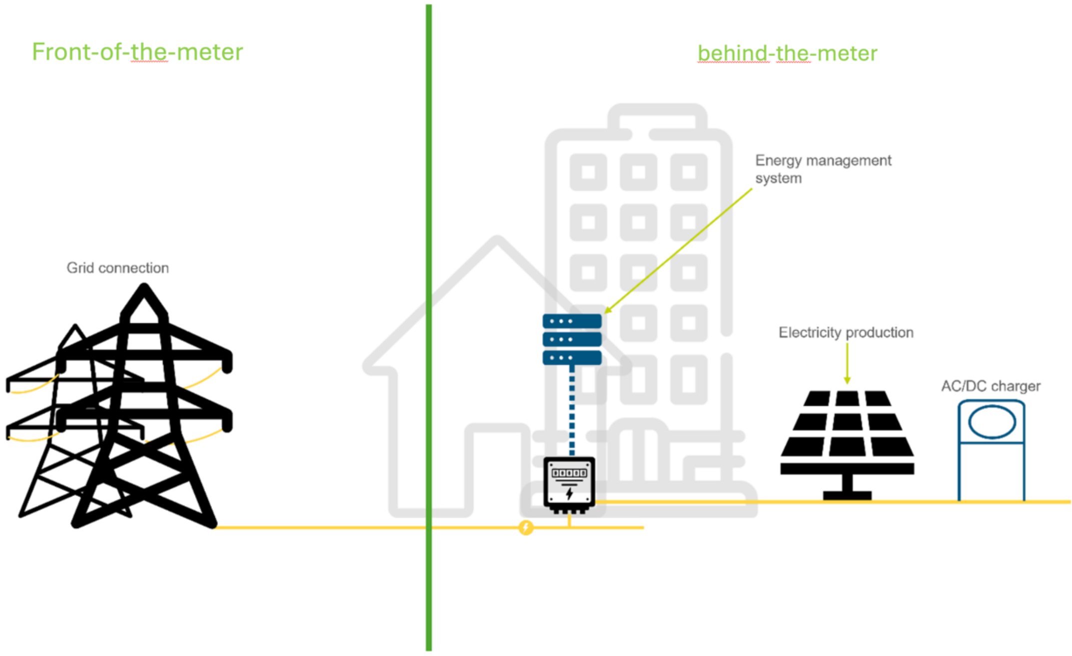


Figure 33: Front and behind the meter aspect

Energy optimization can be performed in 2 different aspects. The first aspect is behind-the-meter optimization, focusing on managing resources and loads within a specific site, such as a residential building, office complex, or charging plazas. This means optimizing everything after the smart grid meter and optimizing all flexible assets which are located behind the local grid meter. In general, this covers all the chargers, battery systems and PV system by deploying multiple predictive algorithms based on measurement data. These algorithms can perform peak shaving, optimize local consumption of local produced energy.

In-front-of-the-meter optimization involves managing the energy flows at a grid-wide level, ensuring the stability and efficiency of the overall electricity system. This includes interactions between the grid operator, distributed energy resources, and EVs connected to the grid. This can be performed based on several systems as congestion management, aFRR, peak shaving, smart charging and V2G.

More information about front-of-the-meter and behind-the-meter concepts can be found in D1.4.
More information about energy services can be found in D3.1.

As in software and algorithms, energy optimization relies heavily on predictive and control algorithms tailored to manage and balance energy resources effectively. Below is a breakdown of how software and algorithms facilitate both behind-the-meter and in-front-of-the-meter optimizations:

11.1.1 Behind-the-Meter (BTM) Optimization

Optimize energy usage within a specific site by managing flexible assets (chargers, battery storage, PV systems) to reduce costs and maximize efficiency.

Software Components:

- **Energy Management System (EMS):** Central software platform integrating all energy resources for monitoring and control.
- **Data Acquisition Layer:** Collects real-time data from sensors, smart meters, and IoT devices.
- **Control Algorithms:** Execute strategies based on analysis and predictions.

Key Algorithms Used:

- **Load Forecasting Algorithms:**
  Predict future energy consumption using machine learning models (e.g., time-series forecasting with LSTM or ARIMA).
- **Peak Shaving Algorithms:**
  Detect upcoming peak demand periods and control energy storage or flexible loads to minimize grid draw. Optimization methods like Linear Programming (LP) or Rule-based control are often used.
- **Demand Response Algorithms:**
  Adjust load in response to pricing signals or grid conditions using predictive models and rule-based controls.
- **Renewable Integration Algorithms:**
  Optimize the use of locally produced energy (e.g., solar PV) using predictive models to match production with consumption.
- **Battery Storage Optimization:**
  Algorithms decide when to charge/discharge batteries based on price signals, demand forecasts, and renewable generation. Reinforcement Learning (RL) can be employed for dynamic decision-making.

11.1.2 In-Front-of-the-Meter optimization

Manage grid-wide energy flows for system stability, congestion management, and efficient energy distribution.

Software Components:

- **Grid Management Systems (GMS):** Coordinate distributed energy resources (DERs), EVs, and grid assets.
- **Advanced Distribution Management Systems (ADMS):** Provide real-time monitoring and control over grid operations.
- **Market Interface Systems:** Interact with energy markets for ancillary services like aFRR (automatic Frequency Restoration Reserve).

Key Algorithms Used:

- **Congestion Management Algorithms:**
  Predict and prevent grid overloads by adjusting supply/demand. Often uses optimization models like Mixed-Integer Linear Programming (MILP).
- **Frequency Regulation (aFRR):**
  Fast-responding algorithms balance supply and demand by controlling DERs and storage systems. Control theory (PID controllers) and model predictive control (MPC) are common.
- **Smart Charging Algorithms:**
  Schedule EV charging based on grid conditions, pricing, and user needs. Algorithms use price-based optimization or AI models to reduce peak demand.
- **Vehicle-to-Grid (V2G) Algorithms:**
  Manage bidirectional charging, enabling EVs to discharge energy back into the grid. Optimization methods balance vehicle battery health, user preferences, and grid needs.
- **Market Participation Algorithms:**
  Enable DERs and storage to participate in energy markets by forecasting prices and optimizing bidding strategies. Techniques include stochastic optimization and game theory.

11.1.3 Integration of Algorithms in Software

1. **Data Processing Pipelines:**
   Handle real-time data streams from sensors, DERs, and market signals.
2. **Predictive Models:**
   Continuously forecast demand, generation, and market prices.
3. **Optimization Engines:**
   Solve complex problems using operations research methods (LP, MILP, stochastic optimization).
4. **Control Logic:**
   Real-time execution of decisions based on optimization outcomes.
5. **Communication Protocols:**
   Enable communication with grid operators, devices, and energy markets (e.g., using OpenADR, Modbus).

Testing software

ElaadNL utilizes Keysight's advanced hardware and software solutions within the SCALE project to test and ensure the interoperability of electric vehicles (EVs) and charging stations in accordance with the ISO/IEC 15118-20 and OCPP standard, amongst others. The SCALE project is dedicated to enhancing smart charging and bidirectional energy transfer, and Keysight's tools provide the precise and robust testing capabilities needed for this mission.

Protocol Testing with Keysight's Conformance Test Solutions

- ElaadNL leverages Keysight’s protocol test tools to rigorously evaluate communication between EVs and charging stations based on ISO/IEC 15118-20 standards. These tools verify critical features, including Plug & Charge, smart charging, and bidirectional energy flow (Vehicle-to-Grid - V2G). By simulating real-world conditions, ElaadNL confirms whether EVs and charging stations securely exchange data, negotiate charging sessions, and manage dynamic charging profiles in compliance with the standard.

Network Emulator Solutions

- Keysight’s network emulation capabilities enable ElaadNL to replicate complex network conditions such as latency, signal degradation, and varying connectivity scenarios. This testing ensures that EVs and charging stations can maintain robust communication under challenging network conditions, a vital requirement of ISO/IEC 15118-20. ElaadNL ensures that charging systems perform reliably and seamlessly in various network environments.

Hardware-in-the-Loop (HIL) Simulation and Test Systems

- ElaadNL uses Keysight’s Hardware-in-the-Loop (HIL) systems to simulate real-time interactions between EVs and charging stations. This setup provides a controlled environment for testing physical and electrical interfaces in line with ISO/IEC 15118-20 requirements. This validation ensures interoperability, safety, and proper communication and energy management processes.

Automated Test Suites and Compliance Testing

- ElaadNL relies on Keysight’s automated test suites to streamline compliance testing. These suites enable efficient testing through automated execution of pre-programmed test cases, detailed result analysis, and comprehensive reporting. This approach helps ElaadNL quickly identify and resolve interoperability issues, supporting the deployment of compliant charging solutions.

Data Analysis and Reporting Tools

- Keysight’s data analysis software provides ElaadNL with in-depth insights into data exchanges between EVs and charging stations. These tools help identify communication errors, optimize interoperability, and ensure alignment with the SCALE project’s goals of enhancing smart and bidirectional charging capabilities.

By using Keysight’s solutions, ElaadNL ensures that the EVs and charging stations tested within the SCALE project achieve high levels of interoperability, reliability, and efficiency under ISO/IEC 15118-20. This work contributes to the advancement of smart charging and Vehicle-to-Grid (V2G) systems for a more sustainable and connected energy future.

12 Monitoring

SCALE data exchange architecture components

Figure 34 presents a detailed overview of the complex data exchange system for smart charging, V2G, and monitoring within the SCALE architecture. This system integrates multiple stakeholders, each contributing and utilizing data to optimize energy distribution, ensure grid stability, and enhance user satisfaction. At the core of this system is the Decision-Making unit, known as the Control Actor, which processes vast amounts of data from various sources to control charging infrastructure and EVs. This central unit is responsible for balancing energy supply and demand, managing grid constraints, and addressing user preferences.

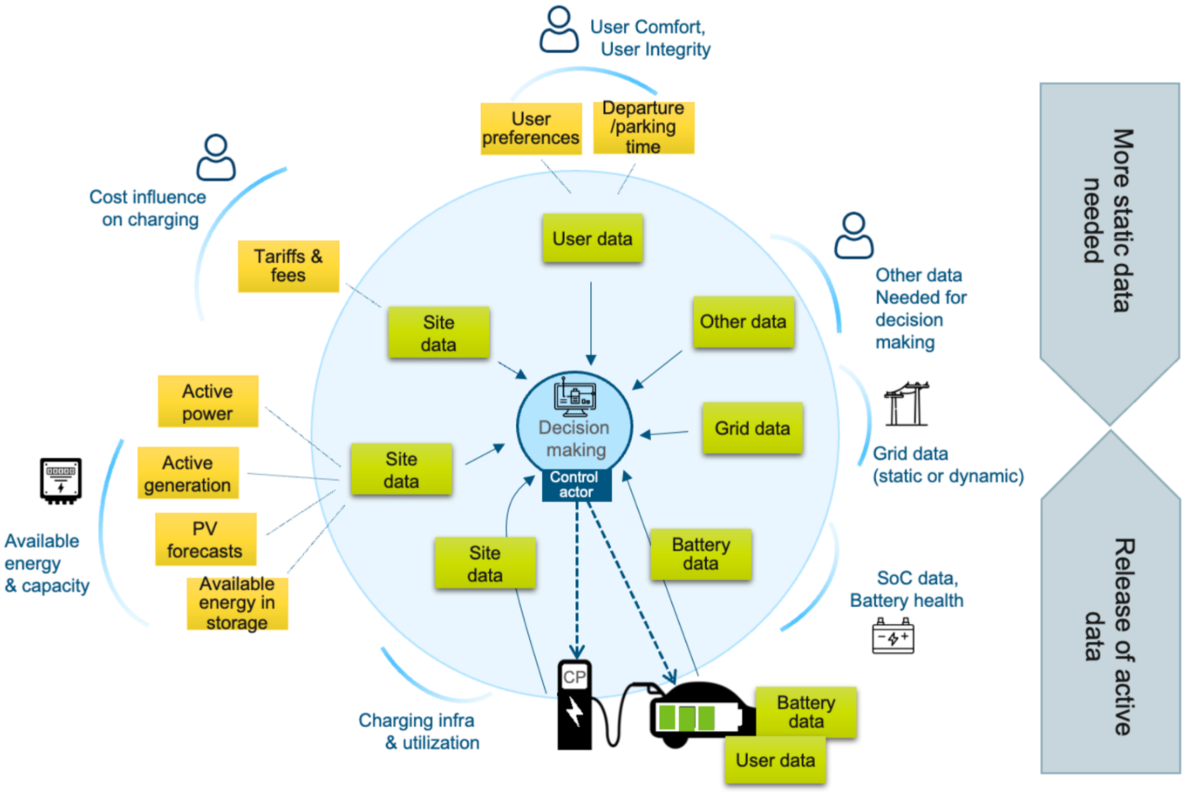


Figure 34: SCALE data exchange architecture

The system handles extensive data inputs, which include user-centric data, site data, grid data, energy availability data, cost data, and other operational data. User data consists of user preferences and departure or parking times, which are crucial for ensuring user comfort and integrity. Battery data, including the State of Charge (SoC) and battery health, plays a significant role in managing V2G services and optimizing charging cycles.

Site data provides insights into the utilization and capacity of the charging infrastructure, helping to prevent overloads and manage available resources effectively. Grid data, both static and dynamic, is essential for maintaining grid stability and integrating renewable energy sources into the system. This data includes frequency time measurements, which are vital for understanding real-time grid performance and ensuring the system's responsiveness to fluctuations in demand and supply.

Energy availability data covers active power, active generation, photovoltaic (PV) forecasts, and available energy in storage. This information allows the system to adapt to real-time energy generation from renewable sources and optimize charging schedules accordingly. Cost data, such as tariffs and fees, influences charging decisions by aligning energy consumption with the most cost-effective periods, thereby supporting both user preferences and grid demands.

The system also incorporates additional data sources categorized as other data, which may include external inputs like weather forecasts, market trends, and operational metrics. Furthermore, some monitoring data is specifically used to audit delivered services such as automatic Frequency Restoration Reserve (aFRR), congestion management, and other ancillary services. This auditing ensures that the services meet required performance standards and contribute to overall grid reliability.

A dynamic transition occurs between using static data for long-term planning and releasing active data for real-time operations. This flexibility allows the system to adapt to immediate grid conditions while maintaining strategic energy management. User comfort and integrity are prioritized through the integration of personalized data, resulting in a user-centered charging experience. Seamless grid integration is achieved through real-time data exchange, supporting advanced services like V2G and demand response. Cost optimization is enabled by analyzing tariffs and aligning charging behavior with favorable pricing periods. Renewable energy is effectively integrated into the system through real-time active generation data and PV forecasts, ensuring sustainable energy use.

Communication protocols are foundational to the system's operation. The Open Charge Point Protocol (OCPP) enables communication between charging stations and the central management system. ISO 15118 provides secure communication between EVs and charging infrastructure, facilitating smart charging and V2G operations. IEC 61850 serves as a standard for grid automation, ensuring efficient interaction with the power grid.

Advanced software and algorithms drive the system’s decision-making processes. Energy Management Systems (EMS) coordinate data from the grid, renewable energy sources, and user preferences to optimize energy distribution. Machine learning algorithms predict energy demand, user behavior, and renewable generation patterns to improve forecasting and system efficiency. Optimization algorithms manage the balance between charging needs, grid constraints, and pricing strategies to maximize operational efficiency.

The system also supports critical energy services. Demand response mechanisms adjust charging behavior based on grid signals, aiding grid stability. V2G services enable electric vehicles to supply power back to the grid during peak demand, offering additional flexibility. Load balancing distributes energy demand across the charging infrastructure to prevent overloads and ensure smooth operation. Monitoring data ensures compliance with service requirements for grid support services like aFRR and congestion management, further enhancing system reliability.

Overall, this highly integrated ecosystem manages vast and complex data streams to balance user needs, grid stability, and renewable energy integration. Through sophisticated data exchange, robust communication protocols, and advanced algorithms, the system ensures efficient, cost-effective, and reliable energy management.

Monitoring of KPI’s

All Key Performance Indicators (KPIs) of the SCALE project can be accurately calculated or measured using the data provided through OCPP, specifically leveraging session and measurement data. OCPP is the standard communication protocol between charging stations and the central management system, ensuring seamless and secure data exchange necessary for monitoring and optimizing the charging infrastructure.

Session data collected via OCPP includes detailed information about each charging session, such as session start and end times, energy consumption, charging duration, user identification, and charging point utilization. This data is essential for tracking infrastructure performance, user behavior, and charging patterns. It allows for the calculation of KPIs related to infrastructure usage, such as charging station occupancy rates, session frequency, energy delivered per session, and user satisfaction metrics.

Measurement data provided by OCPP includes real-time and historical metrics on power flow, voltage, current, and energy transferred during charging sessions. This data is critical for evaluating system efficiency, energy losses, grid interaction, and the impact of Vehicle-to-Grid (V2G) operations. Measurement data also supports the calculation of KPIs related to energy efficiency, grid stability, and the integration of renewable energy sources by providing insights into active power usage, peak load management, and energy distribution.

By integrating session and measurement data, the system can comprehensively monitor and assess all aspects of charging infrastructure performance. This includes calculating technical KPIs like energy throughput, infrastructure availability, and system reliability, as well as service-related KPIs such as cost efficiency, and response time to grid signals. Furthermore, this data enables auditing and validation of grid support services like aFRR and congestion management, ensuring compliance with service-level agreements and performance targets.

In summary, the data generated through the OCPP protocol serves as the foundation for calculating and monitoring all project KPIs. It provides the necessary insights to evaluate technical performance, operational efficiency, user engagement, and the effectiveness of grid services, making it an indispensable tool for achieving the project’s objectives.

More information on the SCALE project KPI’s can be found in D4.2

Different datastreams of renewable assets

In the context of smart charging, Vehicle-to-Grid (V2G), and grid management, it is essential that different data streams from renewable assets such as photovoltaic (PV) systems, battery storage systems, and electric vehicles (EVs) participating in V2G are harmonized to the same data frequency—or even faster data sampling rates—to enable effective decision-making and control. These renewable assets generate diverse data types, including power output, storage capacity, state of charge (SoC), and grid interaction metrics, all of which must be synchronized for optimal system performance.

The decision-making speed of the system is constrained by the data stream with the lowest frequency. For example, if PV data is updated every 10 minutes, battery system data every minute, and EV data every second, the overall system’s responsiveness will be limited by the slowest data source—in this case, the PV data. This delay can hinder the system’s ability to react to rapid changes, potentially leading to inefficiencies in energy distribution or missed opportunities for grid support.

Standardizing and increasing data sampling frequencies across all assets ensures faster, more accurate decisions. This is crucial for services requiring rapid response, like frequency regulation (aFRR) and congestion management, leading to better grid stability, renewable integration, and energy efficiency.

By ensuring that all data streams—from PV systems, battery storage, and V2G-enabled EVs—are harmonized to the same or higher frequency, the system can make faster, more accurate decisions. This leads to improved grid stability, better utilization of renewable energy, and more efficient operation of the overall energy ecosystem.

Facilitation of monitoring data of use-cases

KPI calculation is most effectively performed locally at each pilot site rather than relying on a complex system to retrieve all data through an external API. Each pilot site operates under different conditions, with varying infrastructure, renewable energy assets, and operational goals. Additionally, many pilot sites are not in production phase, making it impractical to invest significant resources in developing and maintaining API connections for data retrieval.

Implementing a centralized API system introduces unnecessary complexity and costs, especially when pilot site owners often lack the in-house expertise to establish and manage secure data connections. This can lead to delays, data integration challenges, and potential security risks.

By calculating KPIs locally, data from on-site systems like PV generation, battery storage, and EV charging can be processed in real-time, allowing for faster performance analysis and immediate insights. Local processing also reduces the risk of data loss or communication failures and avoids the need for complex data standardization across diverse sites.

This approach ensures that each pilot site can focus on optimizing its unique operations without the burden of connecting to external systems, enabling more efficient, cost-effective, and scalable KPI monitoring and reporting.

Monitoring and simulating grid impact of smart charging

A tool has been developed in Task 2.6 to monitor and simulate the city-wide grid impact of the rollout of smart charging and V2G. This tool allows users to simulate scenarios that consider different EV adoption rates, different EV charging strategies and different photovoltaic and heat pump adoption rates. It provides insight into the future grid load at a high number of transformer stations.

In this task, simulation code has been developed in the Anylogic software package, using the QGIS software package to load the required building data into Anylogic. Details about the developed code are provided in D2.6.

13 Lessons learned

Adoption of Standards and Interoperability:

The lack of full adoption of ISO 15118-20 across the industry has created challenges in achieving seamless interoperability. Many OEMs and charger manufacturers rely on proprietary adaptations of ISO 15118-2, resulting in fragmented implementations that hinder broader functional use. The partners who started early in the project implementing the ISO 15118-20 early in the project bounced into some issues. Therefor they started modifying or adding messages to the ISO 15118-2. Partners who started implementing the ISO 15118-20 in a later stadium did use the correct standard for V2G and smart charging purposes.

Add-ons to ISO 15118-2 were utilized to enable some V2G functionality during the project, but these serve only as temporary measures and emphasize the importance of advancing ISO 15118-20 adoption.

Collaboration and Data Management:

Data handling of thousands of chargers which are pooled is challenging if they need to comply with the TSO, DSO requirements regarding sending updates and react to setpoints. Effective data management is critical for scaling V2G and smart charging solutions. Lessons from the pilots demonstrated that delta monitoring is essential for managing pooled charger data exchange to prevent excessive data load and data cost.

Scalability and Feasibility:

aFRR services need a very fast response once an activation from the TSO is received. This means the activation needs to be translated into setpoints for chargers, and the EVs need some time to react. This makes it challenging to perform such an end to end response. Next to that, delta monitoring is needed for data reduction of the pool of chargers. aFRR services, demonstrating scalability potential when site-specific use cases are prioritized.

On the other hand, FCR services are only feasible with local measurements and control at the charging station level. Localized management also enhances the delivery of congestion management and automatic Alternative methods to achieve pilot goals should be derived based on learnings from these implementations, ensuring flexibility for different operational environments.

Technical Insights

Real-world scenarios often differ significantly from theoretical setups, such as the risk of EVs being indefinitely unreachable after a pause in operations during a charging session. Optimization algorithms need to accommodate these practical challenges. These insights have resulted in a test protocol set-up by Elaad for validating and reporting the results for all tested vehicles as a group.

The project found that users are indifferent to smart charging specifics, as long as their vehicles are fully charged by the end of their sessions, underscoring the need for user-centric designs.

Advancing OpenADR and OCPI Protocols:

OpenADR, now being adopted by DSO consortia, shows opportunities for replacing OCPI in specific applications. Compatibility between OpenADR and platforms like Equigy remains a topic for further investigation and harmonization.

Beginning the implementation of OpenADR alongside existing OCPI protocols provided insights into streamlining demand response signals, but further refinement is needed for widespread adoption.

Monitoring and Measurement Challenges:

Delta monitoring theoretics promise in estimating charging behavior using vehicle amperage measurements. However, the expertise limited the implementation, highlighting the need for robust skill sets in handling real-time data streams.

Aligning 15-minute aggregated data with 4-second real-time data remains a complex challenge, due to the base data of the chargers is only 15 minutes. In case the value-add of the comparison between 15-minute data and 4-second data becomes apparent, further research for integration and visualization issues could be done by Equigy, Enervalis and We Drive Solar.

By addressing these lessons learned, the SCALE project can refine its approach to developing interoperable, scalable, and user-friendly V2G and smart charging solutions. These insights provide a strong foundation for overcoming market barriers and accelerating the adoption of innovative energy technologies.

14 Conclusions

The SCALE project has made significant progress in advancing V2G and smart charging technologies, showcasing the technology and building a blueprint by contributing to the EU's broader goals of sustainable energy transition. Deliverable D2.4 demonstrates the collaborative efforts across stakeholders, from hardware innovations to software architecture development to an ecosystem ensuring that the foundations for scalable, interoperable, and future-proof energy solutions are in place.

Despite challenges, such as the incomplete adoption of ISO 15118-20 and the reliance on proprietary implementations by OEMs and charging infrastructure manufacturers, the project highlights the critical importance of harmonized standards. By fostering collaboration among key players, SCALE ensures that innovative solutions can bridge gaps in the ecosystem, delivering functional, secure, and user-centric outcomes. The pilots in various cities have illustrated the potential for tailored implementations, addressing both urban and rural energy demands.

As SCALE moves forward, continued focus on interoperability, standard compliance, and market readiness will be key to unlocking the full potential of V2G technologies, driving Europe towards a resilient and renewable energy future.