# Update interoperability testing

Project deliverable D2.5

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

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# 1 Deliverable administrative information

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|---|---|
| **Deliverable number** | D2.5 |
| **Deliverable title** | Update interoperability testing |
| **Dissemination level** | Public |
| **Submission deadline** | 31-05-2025 |
| **Version number** | V1.0 |
| **Authors** | Remi Keijsers (ElaadNL), Karima Boukir (Enedis), Jordan Sautreau (Trialog) |
| **Internal reviewers** | Robert Italiaander (ElaadNL) |
| **Document approval** | Baerte de Brey (ElaadNL) |

## 1.1 Legal Disclaimer

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# 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)
- Paris Area (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
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- Urban Electric Mobility Initiative UEMI DE
- Renault FR
- Chalmers University SE
- Polestar SE
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# 4 Deliverable executive summary

## 4.1 Summary

The SCALE project (Smart Charging Alignment for Europe), funded by the European Union's Horizon Europe programme, is designed to facilitate the large-scale deployment of electric vehicles (EVs) and to prepare the broader European market—including industry, infrastructure providers, and public authorities—for smart and bidirectional charging integration. Deliverable D2.5 presents a comprehensive update on interoperability testing activities within the project, focusing on critical components such as EVs, charging stations (EVSEs), charging management systems (CSMS), and their interface with the electricity grid.

The primary aim of this deliverable is to evaluate the interoperability of different components across the charging ecosystem by testing real-world and simulated devices in both communication and power-related scenarios. These tests are grounded in the application of open international standards, specifically ISO 15118-20 for communication between EVs and EVSEs, and OCPP 2.0.1/2.1 for communication between EVSEs and CSMS platforms. Testing was conducted in collaboration with leading European laboratories—ElaadNL (Netherlands), Enedis (France), and the Joint Research Centre (Italy)—and supported by automotive and technology partners including Renault, Hyundai, Polestar, ABB, Trialog, Enervalis, and WeDriveSolar.

The testing activities demonstrated key V2G functionalities using ISO 15118-20 and OCPP 2.0.1/2.1, with both AC and DC charging and discharging scenarios tested across different equipment types. Grid-related parameters and power quality conditions, such as overvoltage, undervoltage, and harmonic distortions, were incorporated using advanced emulation tools. Live demonstrations were conducted during three V2X symposia, as well as within the large-scale bidirectional ecosystem in Utrecht, offering valuable real-world insights into V2X deployment. Further validation of full communication chains—spanning from CSMS to EV—highlighted the technical feasibility of safe and efficient bidirectional energy transfer.

Despite these advances, the testing exposed several challenges. Interoperability issues were frequently linked to early-stage or proprietary implementations of the standards. TLS encryption in ISO 15118-20 created additional complexity for several stakeholders, and bidirectional switching during active sessions was not consistently supported. While power quality during discharging closely mirrored that of conventional charging, some deviations reinforced the need for further validation and alignment with grid codes.

To address these challenges and accelerate market readiness, the deliverable outlines a set of policy recommendations. These include the need for mandatory conformance testing using finalized (versions of) standards, the harmonization of certification requirements for EVs and EVSEs under applicable grid codes, and greater regulatory clarity on component-level responsibilities. Furthermore, long-term operational funding for public test laboratories is essential to maintain high-quality testing infrastructure and expertise. Public procurement guidelines should prioritize infrastructure tested and validated by accredited labs to ensure quality, promote interoperability, and support a level playing field for all market participants.
The document also emphasizes the importance of a (European, international) coordination framework for interoperability, which could serve to align testing methodologies, support test result harmonization, and integrate with broader regulatory efforts such as ACER's network code development. Active engagement in international collaborations, such as IEA Task 53, is encouraged to facilitate knowledge exchange and global harmonization.

In summary, this deliverable underlines the essential role of interoperability testing in enabling a resilient and scalable V2X ecosystem. The SCALE project's activities provide a solid foundation for Europe's transition toward smarter, integrated electric mobility—ensuring that vehicles, charging systems, and grid infrastructure can operate in a seamless, secure, and standards-compliant manner.

## 4.2 Key Words

Electric vehicles, smart charging, bidirectional charging, V2X, V2G, interoperability, flexibility, protocols, OCPP, ISO 15118

# Table of Contents

# 5 List of abbreviations and acronyms

| Acronym | Meaning |
|---|---|
| AC | Alternating Current |
| BESS | Battery Energy Storage System |
| CDS | Charge Discovery System |
| CSMS | Charging Station Management System |
| CPO | Charge Point Operator |
| DC | Direct Current |
| EN | European Standard |
| EV | Electric Vehicle |
| EVSE | Electric Vehicle Supply Equipment |
| IEC | International Electrical Commission |
| ISO | International Organization for Standardization |
| MitM test | Man in the Middle test |
| OCPP | Open Charge Point Protocol |
| PCB | Printed Circuit Board |
| PHEV | Plug-in Hybrid Electric Vehicle |
| PKI | Public Key Infrastructure |
| TCP | Transmission Control Protocol |
| TLS | Transport Layer Security |
| V2G | Vehicle-to-Grid |
| V2L | Vehicle-to-Load |
| V2X | Vehicle-to-Everything |
| VELA | Vehicle Emissions Laboratory |
| | |

# 6 Purpose of the deliverable

The main goal of the SCALE project is to enable and facilitate the mass deployment of electric vehicles and the accompanying smart charging infrastructure, while making it an open smart charging & V2X ecosystem that equally benefits users, cities & regions, businesses, and society at large. To achieve this, SCALE brings together leading existing research & innovation initiatives and smart charging demonstration testbeds from across Europe forming a unique knowledge & collaboration platform.

This deliverable focuses on Task 2.5 “Interoperability testing”, which is part of Work package 2 “Development of Smart Charging and V2X technologies and solutions”.
The overall goal of this Task is to test the interoperability between devices, components and actors and see if the processing & exchange of information takes place as intended, with a special focus on Smart- and bidirectional charging. As during the project the interoperability with the electricity grid was also identified as an important factor, this has been included in the testing as well. The goals of this task all contribute to the main goal of enabling the mass deployment of electric vehicles and the accompanying smart charging infrastructure in an open manner. Interoperability regarding communication makes sure that a lock-in with a single supplier can be prevented, and by testing the interoperability with the grid lessons are learned about preventing grid or charging issues while massively connecting electric vehicles and charging infrastructure with the grid.

To achieve the goals, several Test Labs are active in this Task, namely the Elaad Testlab, the ENEDIS labs and the EC’s Joint Research Centre (JRC). These collaborate and share information and therefore contribute to the SCALE goal of creating a knowledge and collaboration platform. The lab environment of Elaad has been used to build test set-ups including the necessary monitoring equipment for gathering test records and logs. The labs of ENEDIS and the JRC have been preparing as well.

This deliverable will give an overview of the different Test labs, their capabilities and test setups, and the overall achievements during the interoperability tests. Also some recommendations are given for policy makers ow to make use of the testlabs in the preparation for mass market, and how the labs can facilitate this. Because the results per actor are under a Non Disclosure Agreement, only the overall results can be shared.

# 7 Test labs and participants in WP 2.5

## 7.1 Elaad Testlab

To ensure the successful integration of electric vehicles with the electricity grid, the ElaadNL non-profit research organization, founded and funded by the Dutch electricity grid operators, has set up the Elaad testlab. Here electric vehicle and charging station manufacturers can bring their devices and have them tested for free on interoperability, smart charging, V2G and power quality. The Elaad testlab is a unique location, with specialized testing and measuring equipment and newly derived testing protocols based on more than 14 years of charging experience at ElaadNL. The Elaad testlab uses the obtained knowledge during testing to advise charging improvements to the manufacturers and to collect “Best practices” and “common mistakes”. The Elaad Testlab wants to help the manufacturers to give a better charging experience to their customers with a reduced impact on the electricity grid. Also, the lessons learned are used to prepare the grid operators for the increase in e-mobility and to improve the standardization and certification of electric vehicles.

Within the Scale project ElaadNL facilitated in/and performed interoperability testing of V2G. Testing partners have been invited to come testing (together) at the Elaad Testlab. Manufacturers could also send their products to the Elaad Testlab where ElaadNL would test V2G interoperability.

## 7.2 Enedis

Enedis is a mission-driven company dedicated to public service, managing 95% of mainland France's electricity distribution to homes. Their goal is to create a connected, efficient, and sustainable network. They also test the impact of charging on "wave quality" to ensure electricity delivery meets power quality standards.

Recognizing the importance of sector collaboration, Enedis works with stakeholders to develop technical structures, standards, and regulations, creating a technically and commercially attractive environment for electric mobility development. To ensure the interoperability of e-mobility services with smart grids, Enedis supports the development of IEC standards. Enedis also participates extensively in research, testing, demonstrations, and standardization organizations. The use of IEC standards ensures cybersecurity, reduces resource costs, and contributes to harmonizing EV charging systems with the services used by Enedis in smart grid management.

Enedis has it’s proper testing labs in Paris area for smart metering roll out and electric mobility testing, mainly to prepare and improve electrification of it’s own fleet. The labs are also made available for collaborations with e mobility stake holders (CPOs, OEMs, chargers manufacturers) for checking their hardware before deployment and use Enedis emulators, to get better experience and minimize the risk of failure on field.

A 2 days SCALE consortium meeting has been hold at the Enedis labs in November 2023, where partners could visit the testing facilities with Enedis experts. On the SCALE demo side, Enedis is involved in 2 use cases :

-The Toulouse use case is about V1G simulations on car depot site for connection power optimisation.
-Another use case is planned in Paris for V2H with PV for self consumption optimisation. This use case is a substitution for the SONO use case and will start after acceptance of the amendment by the European Commission. In this use case OCPP2.1 has been implemented and tested successfully with TRIALOG emulator system. Next step will be to connect full hardware (V2G EV + V2G charger) and software components for a full ’V2H’ smart controllable chain.

With regards to V2G use case, Enedis network connected, in 2024, first V2G EVs from Renault (R5) into the grid using Linky smart Meter for the settlement on the electricity market. For more details see Renault's presentation at V2X Elaad's symposium. Symposium: V2X (Vehicle to anything) • Events • ElaadNL.

In addition, Enedis has access to EDF R&D labs and their experts for different complementary testing related to wider topics for robustness of Electrical grids as a whole.

## 7.3 Joint Research Centre

The JRC provides independent, evidence-based knowledge and science, supporting EU policies to positively impact society. The JRC plays a key role at multiple stages of the EU policy cycle. It contributes to the overall objective of Horizon Europe.

JRC works closely with research and policy organizations in the Member States, with the European institutions and agencies, and with scientific partners in Europe and internationally, including within the United Nations system.

Vehicle Emissions Laboratories (VELA), also known as the European Interoperability Center for Electric Vehicles and Smart Grids, is a test lab in Italy and part of the Joint Research Centre (JRC) of the European Commission. VELA combines four new, state-of-the-art laboratories, which bring together knowledge and test facilities in the areas of functionality, efficiency, range, hybrid exhaust emissions, electromagnetic compatibility, smart grids, battery testing and emissions of electric vehicles. VELA 9, which is the "E-Mobility Electromagnetic Testing Facility, is one of such laboratories. VELA 9 is a chamber designed for electromagnetic compatibility testing of light-duty vehicles and light commercial trucks. This chamber is cladded with absorber material, that suppresses any kind of electromagnetic echo inside. Reception antennas and receivers analyze the electromagnetic emissions generated by electric and hybrid cars during their full range of acceleration, driving and recuperative breaking, and also during the battery re-charging phase, as well as their wireless communication with smart grids. VELA 9 and its powerful amplifiers, along with radiating antennas inside the chamber, is also capable of testing the immunity of the electric vehicles against external electric or magnetic fields, from meter-wave to radar pulses. As electric vehicles and all supply devices of the future electro-mobility are “connected”, the avoidance of interferences is essential.

The research conducted at all the VELA laboratories focuses on sustainable transport and climate change related to vehicle use, fuel consumption, and emissions. The VELA laboratories include a climate chamber, where tests can be conducted under various (extreme) temperatures, ranging from -30°C to +50°C, providing insights into the performance of electric and hybrid vehicles under cold and hot conditions.

## 7.4 Renault

As a visionary, innovative company, Renault Group has been at the forefront of mobility since 1899.

Today, the Group is transforming its business model to become a next-generation, high-tech, low-carbon automotive company, working with its four brands – Renault, Dacia, Alpine and Mobilize, and specialist entities to shape the future of mobility.

Smart, safe and affordable electric vehicles are developed by Ampere (part of Renault Group) including the recent R5 E-TECH with brand new V2G AC capabilities. The launch of R5 E-TECH came with the launch of V2G energy offer for European customers offering flexibility on the grid and lowering the energy costs for the users. The use of V2G AC in public infrastructure is a logical step forward towards the future of energy management in smart cities.

As a partner for SCALE, Ampere has been supplying an implementation guide to allow V2G operation with WeDriveSolar charger but also two R5 E-TECH prototypes with V2G AC capabilities to ensure real experimentation in the city of Utrecht.

## 7.5 Hyundai Motor Group

Hyundai Motor Group is a global leader in the automotive industry, renowned for its dedication to technological innovation and sustainability. Headquartered in South Korea, Hyundai's portfolio includes brands like Hyundai and Kia, both of which are actively pioneering advancements in electric vehicles (EVs), autonomous driving, hydrogen fuel cells, and advanced battery technology. These efforts are part of Hyundai's broader strategy to promote clean, efficient, and interconnected mobility solutions worldwide, with specific initiatives tailored to local needs and infrastructures.

In the Netherlands, Hyundai is playing a pivotal role in advancing sustainable energy practices and smart mobility solutions. Through strategic partnerships and pilot projects, Hyundai is actively involved in developing and testing technologies like Vehicle-to-Grid (V2G) and Smart Charging (V1G) systems. Smart Charging (V1G), or unidirectional smart charging, allows Hyundai's EVs to adapt their charging rates based on real-time grid conditions. Hyundai already introduced it's own SmartCharging app (V1G) in the Netherlands available for all Hyundai EV/PHEV owners.

The Vehicle-to-Grid (V2G) initiative, currently being tested by Hyundai in Utrecht, adds an even greater dimension to sustainable mobility by enabling bidirectional energy flow between EVs and the power grid. This means that Hyundai EVs equipped with V2G capabilities can not only charge from the grid but also discharge electricity back into it when needed. This system is especially valuable in a country like the Netherlands, where renewable energy sources, such as wind and solar, contribute significantly to the power grid. By allowing EVs to store excess renewable energy and feed it back during high-demand periods, V2G can help stabilize the grid, reduce reliance on fossil fuels, and lower energy costs for users.

## 7.6 Polestar

Polestar (Nasdaq: PSNY) is the Swedish electric performance car brand determined to improve society by using design and technology to accelerate the shift to sustainable mobility. Headquartered in Gothenburg, Sweden, its cars are available in 27 markets globally across North America, Europe and Asia Pacific. Polestar is scheduled to expand into additional markets in 2025.

Polestar has three models in its line-up: Polestar 2, an electric performance fastback; Polestar 3, the SUV for the electric age; and Polestar 4, the SUV coupé transformed. With plans to have a line-up of five performance EVs by 2026, Polestar 5, an electric four-door GT and Polestar 6, an electric roadster, are coming soon.

The Polestar 0 project supports the company’s ambitious goal of creating a truly climate-neutral production car by 2030. The research initiative also aims to create a sense of urgency to act on the climate crisis, by challenging employees, suppliers and the wider automotive industry, to drive towards zero.

Polestar is actively advancing the development of Smart Charging and Vehicle-To-Grid (V2G) technologies through laboratory research and pilot projects in Sweden. Demonstration sites have been established at Chalmers University and Polestar’s facilities, where focus have been on testing and refining AC and DC bidirectional charging functionality. To support these efforts Polestar has modified Polestar 2 vehicles with specialized equipment, enabling bidirectional charging capabilities.

These initiatives highlight Polestar's commitment to shaping a sustainable energy ecosystem, leveraging Smart Charging and V2G to optimize energy use, support grid stability, and enhance the overall value proposition of electric vehicles. By integrating these cutting-edge technologies, Polestar not only demonstrates its technical leadership but also underscores the potential for EVs to play a critical role in the transition to renewable energy systems.

## 7.7 ABB

ABB is a global technology leader in electrification and automation, enabling a more sustainable and resource-efficient future. With over 140 years of history and more than 105,000 employees worldwide, by connecting its engineering and digitalization expertise, ABB helps industries run at high performance, while becoming more efficient, productive and sustainable so they outperform. At ABB E-mobility, it's our mission and purpose to power e-mobility forward. As the partner for SCALE project, ABB E-mobility designed and manufactured compact V2G DC chargers that can discharge EV battery when commanded to do so by operator with charge protocol ISO15118-20, which becomes a vital element to increase flexibility in the E-mobility industry.

## 7.8 Enervalis

Enervalis plays a pivotal role in software development for energy management and smart charging solutions. As a 100% subsidiary of ABB E-mobility, Enervalis leverages its expertise to drive innovation in energy systems.

With the Terra Gateway Pro, ABB's advanced energy management system, Enervalis is unlocking state-of-the-art energy management solutions across various pilot sites. These solutions include asset management for energy storage, EV chargers, and renewable energy systems such as photovoltaic (PV) installations. By developing sophisticated algorithms and forecasts, Enervalis optimizes onsite energy flows based on demand, enabling smart, bidirectional charging and addressing unpredictable load requirements. All data is seamlessly captured and presented to end-users via an intuitive, user-friendly portal.

Within the SCALE project, Enervalis leads Work Package 2 and is actively involved in protocol analysis, KPI monitoring, and supporting pilot sites. Key pilot sites include VDL in Eindhoven and three locations in the Budapest area managed by EMS and DBH. At these sites, the Terra Gateway Pro is installed to control onsite energy assets and optimize energy usage through smart and bidirectional charging, facilitated by ABB's V2G DC charger. Besides that, Enervalis also provides the central optimization of the Utrecht use-case as well as the testing for delivering congestion services and AFRR services

## 7.9 We drive Solar

In Utrecht, the Netherlands, a world-wide unique bi-directional ecosystem is created which is the largest V2G living lab in the world. It consists of (at the time of writing) about 700 AC-bidirectional charging stations and almost 400 smart-charging shared EVs. The 'Utrecht bidirectional Ecosystem' supports power system stability, supplies flexibility to the electricity grid with the goal to reduce / postpone grid reinforcement costs and lowers the peak load of the power system, and it is a major driver for innovation and upscaling of AC-V2G technology.

This use case has been set up to prove the potential benefits – electricity grid robustness, urban environment benefits, when AC-V2G services are scaled up – which is the plan of City of Utrecht, We Drive Solar and EV sharing partner MyWheels for the coming years.

Unique is that the pilot is based on a fleet of shared V2G cars which is owned by a single professional entity, this enables easy bundling, intelligent charging management and fast upscaling of innovations. Part of the 700 V2G chargers is operated to charge these shared cars, which are 'station based', which means that they are always connected to their V2G charger and available for smart and V2G charging whenever not booked. Most of the other V2G chargers are active as 'normal' on-street public charging also for non-V2X ready cars.

We Drive Solar is the developer and operator of the AC-V2G charging points in this living lab, which will be operational starting March 2025 as a bidirectional ecosystem with 50 V2G Renault 5 and the new version of the WDS AC-V2G charging stations, and will grow to 500 V2G Renault 5 cars by end of 2025.

In Task 2.5, We Drive Solar has tested the V2G interoperability between the new V2G chargers and the V2G Renault 5. This was done at WDS and its partners in NL, at Renault Technocentre in Paris and at the Elaad Testlab.

## 7.10 Trialog

Trialog is a consulting company providing expertise in energy and electromobility domains. It helps its customers to integrate today's innovations by providing engineering support, training and tools and prepares tomorrow's innovations by actively contributing to research and innovation projects.

Within SCALE, Trialog provides its expertise on interoperability of communication protocols required for this project (OCPP, ISO 15118) and its testing tools to ease deployment for the pilots, such as EV and charging station simulators implement ISO 15118-20. Finally, a charging station using Trialog' software implementation of ISO 15118-20 has been deployed in Elaad test lab.

## 7.11 Other testlabs and initiatives

Above the consortium partners are mentioned who participate in WP 2.5 of the SCALE consortium. Many more players are active in this field. Without having the intention of giving a complete overview, this subparagraph tries to give a insight of other relevant players and gives a first suggestion for categorization, to understand where strengths and interests lay.

### 7.11.1 Commercial Independent Test Labs

These laboratories offer fee-based services to various clients across the EV charging ecosystem. Some examples include:

- TÜV Rheinland (Germany, Global)
  Focus: Functional safety, electromagnetic compatibility (EMC), charging interoperability (AC/DC), ISO 15118, OCPP, CE conformity.
  Specialties: Cybersecurity, plug & charge, EVSE certification.
  Clients: Original Equipment Manufacturers (OEMs), Charge Point Operators (CPOs), charger manufacturers.
- DEKRA (Germany, Spain, China, etc.)
  Focus: Interoperability testing (EV and EVSE), ISO 15118, CHAdeMO, OCPP, safety certification.
  Specialties: High-voltage safety, grid compliance, international type approvals.

- UL Solutions (USA, EU)
  Focus: EVSE compliance with IEC/UL standards, safety, communication protocols.
  Specialties: Cybersecurity (UL 2900), product certification for North America and Europe.
- Intertek (Global)
  Focus: Product safety, grid code compliance, EV charging systems.
  Specialties: Environmental testing, durability, EMC.

### 7.11.2 Development Labs by Industry

These are internal laboratories operated by industry players such as OEMs, CPOs, Charger Manufacturers for development and validation purposes. They are not open but play a vital role in innovation and quality assurance. Traditionally, the test labs of major car manufacturers focused on optimizing internal combustion engines—measuring emissions, fuel efficiency, and performance under various driving conditions. These facilities were key in meeting environmental regulations and improving engine technology. Today, as the industry shifts to electric vehicles (EVs), the role of test labs is evolving rapidly. Engineers are now testing batteries, electric drivetrains, charging systems, and energy management software. With EVs becoming integrated into the broader energy ecosystem—interacting with the grid, storing renewable energy, and enabling vehicle-to-home or vehicle-to-grid solutions—new types of testing are essential. Modern test labs must now simulate not just road conditions, but also complex energy flows and smart grid interactions. In previous paragraphs the labs operated by Renault, Hyundai, Polestar and ABB are good examples of development labs by industry.

### 7.11.3 Test Labs Operated by Grid Operators

These labs are managed by grid operators to ensure compatibility and integration of EV charging with the electrical grid. Apart form the previous mentioned labs by Elaad and Enedis, the testlab by Terna deserves attention. Terna, Italy's national electricity transmission operator, has established the E-mobility Lab in Turin to explore how electric vehicles (EVs) can support the power grid through Vehicle-to-Grid (V2G) technology. This initiative is part of a collaboration with Fiat Chrysler Automobiles (now part of Stellantis) and ENGIE Eps.

The E-mobility Lab is designed to test the capabilities of EVs and charging infrastructure in providing grid services such as frequency regulation, reserve power, and energy time-shifting. It features 13 charging stations capable of both AC and DC charging, supporting bidirectional energy flow up to 500 kW. The lab is open to various e-mobility stakeholders interested in testing their products or prototypes for optimal vehicle-grid integration.

In addition to the lab, a large-scale V2G charging hub has been developed at the Mirafiori industrial complex in Turin. This facility includes 32 bidirectional fast-charging stations, enabling up to 64 vehicles to charge and discharge energy simultaneously.

These efforts reflect a broader shift in automotive testing and energy management, where EVs are not only modes of transportation but also active participants in energy systems. By integrating EVs into the grid, the E-mobility Lab and associated projects aim to enhance grid stability, support renewable energy integration, and provide economic benefits to EV owners through energy services.

### 7.11.4 Government & EU Research Labs

These laboratories are government-funded and focus on research, policy support, and standardization. Some examples are:

- JRC – Joint Research Centre (European Commission, Italy)
  Type: Government research lab.
  Focus: Policy support, interoperability, emissions, smart grid integration.
  Specialties:
  - VELA 9 EMC chamber: EV emissions & immunity
  - Power quality: bidirectional charging scenarios
  - Grid emulation, hardware-in-the-loop testing
- NREL – National Renewable Energy Laboratory (USA)
  Type: U.S. Department of Energy.
  Focus: EV-grid integration, smart charging, cybersecurity.
  Specialties:
  - Real-time grid simulation
  - V2G, V2H modeling
  - Standards testing (SAE J3068, ISO 15118, OCPP)
- Argonne National Laboratory (USA)
  Type: U.S. Department of Energy.
  Focus: EV charging infrastructure, interoperability, and grid integration.
  Specialties:
  - Smart Energy Plaza: real-world testing of EV-grid integration, including V2G, V2B, and V2X scenarios.
  - Development of harmonized EV charging device specifications and test procedures.
  - Participation in the ChargeX Consortium to improve public EV charging experiences.

### 7.11.5 Academic & Research Institutions

These institutions conduct research and development in EV charging technologies and are often linked to a university or other not-for-profit institution. Some examples are:

- SEEL – Swedish Electric Transport Laboratory (Sweden)
  Type: Joint venture between Chalmers University of Technology and RISE Research Institutes of Sweden.
  Focus: Research and development in electromobility.
  Specialties:
  - Testing of batteries, electric machines, and complete vehicles.
  - Safety-critical testing and development of new charging and energy storage technologies.
  - Facilities located in Gothenburg, Borås, and Nykvarn.

#### 7.11.6 Government-Affiliated Test Labs in India

These laboratories are affiliated with the Indian government and focus on testing and certification of EV technologies.

- ARAI – Automotive Research Association of India
  Type: Autonomous body under the Ministry of Heavy Industries, Government of India.
  Focus: EV development, testing, and evaluation.
  Specialties:
    - Testing requirements as per IS 17017 standards.
    - Challenges related to the interoperability of Electric Vehicle Supply Equipment (EVSE).
    - Development of simulators for simulation of electric vehicle environments for offline testing of charging stations.
    - Validation of protocols to ensure interoperability of DC chargers.
    - Evaluation of electric vehicle conductive chargers (AC/DC) under various environmental conditions.
    - Testing and certification of EV components, including batteries and chargers.

#### 7.11.7 International Energy Agency Task 53

The International Energy Agency's (IEA) Task 53 is an initiative under the IEA's Hybrid and Electric Vehicles Technology Collaboration Programme (HEV TCP), focused on testing and validating electric vehicle charging infrastructure. The task aims to harmonize global test procedures, support standard implementation (e.g. ISO 15118, OCPP), and facilitate interoperability across EVs, EVSE, and energy systems. By fostering collaboration among research institutions, test labs, industry, and policymakers, Task 53 helps accelerate the reliable rollout of smart and bidirectional charging technologies, ensuring they meet technical, safety, and grid-integration requirements worldwide.

# 8 V2G Symposium

In an effort to showcase the advancements in Vehicle-to-Grid (V2G) technology, three symposiums were organized in which live demonstrations of the V2G applications to a broad audience was given. These events provided valuable insights into the practical applications of V2G.

## 8.1 First Symposium: March 28, 2023

The first symposium took place on March 28, 2023, and featured a live demonstration of both Vehicle-to-Load (V2L) and Vehicle-to-Grid (V2G) functionalities.

The event began with a demonstration of V2L, where an electric vehicle (EV) was used to power an electric kettle to boil water for a cup of tea. This simple yet effective demonstration showed how energy stored in the EV's battery could be transferred to power an external device.

Following this, the same EV was connected to an AC charger, and the V2G functionality was demonstrated. The EV fed energy back into the electricity grid, illustrating the concept of using EVs not just as consumers of energy, but as active participants in the grid, offering the potential to help stabilize the electrical system.

It is important to note that the technology demonstrated in this symposium was developed prior to the official release of ISO 15118-20, which is a communication standard between vehicle and charger that is needed for V2G. As such, the communication protocol used for V2G in this demonstration was based on a committee draft version of the ISO standard. Consequently, the demonstration was only compatible with a small group of custom-made EVs and a limited number of custom-made charging stations.

The recording of this demonstration can be found on the Elaad YouTube channel at the following link:

https://www.youtube.com/watch?v=JyZzXOrt4K8

## 8.2 Second Symposium: April 3, 2024

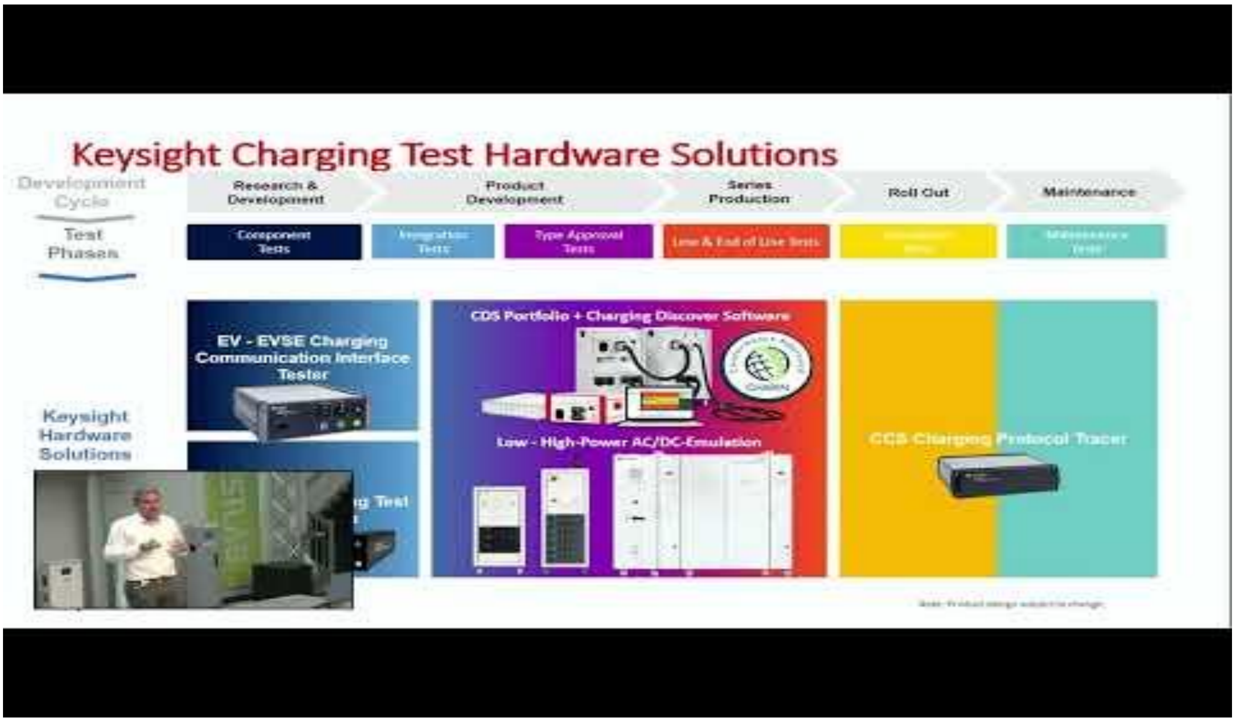
The second symposium, held on April 3, 2024, built upon the previous year's demonstration, this time incorporating the final communication protocol of ISO 15118-20. The demonstration focused on the operation of a V2G AC charging station with the updated protocol, marking a significant advancement in the interoperability of V2G systems.

In this demonstration, the system was tested against the Elaad test system built by Keysight, which allows for the emulation of a V2G vehicle. This system enables testing and validation of V2G functionality, providing insights into how these systems interact under real-world conditions. Further details on the operation of this test system are provided in Chapter 10.2.1.3.

What made this demonstration unique compared to the 2023 event was the use of an open communication protocol, based on ISO 15118-20. This open standard facilitates interoperability between different electric vehicles and charging stations that also support the protocol, paving the way for broader adoption and integration of V2G technology across various manufacturers and models.

The video of this demonstration can be accessed at the following link:

https://www.youtube.com/watch?v=5k4GxkIDQss




## 8.3 Third Symposium: May 29, 2024

On May 29, 2024, ElaadNL hosted the V2X (Vehicle-to-Everything) Symposium at its Testlab in Arnhem. The event focused on the potential of EVs to serve as energy buffers, contributing to grid stability and sustainability.

The symposium began with the presentation of the PwC report, Unlocking EV Smart Charging to Reduce Grid Congestion – Lessons from the Netherlands, which highlighted regulatory challenges and the need for standardized data exchange to facilitate smart charging and V2X applications.

Key discussions included the technical requirements for V2X implementation, the role of Distribution System Operators (DSOs) in accommodating V2G (Vehicle-to-Grid) technologies, and the importance of aligning charging infrastructure with grid codes. Speakers from organizations such as Stedin, E.DSO, and the Open Charge Alliance provided insights into these areas.

A live demonstration of bi-directional charging showcased the practical application of V2X technology, illustrating how EVs can supply energy back to the grid or a private home, thereby balancing energy demand and supply. The event also featured presentations from automotive manufacturers like Renault and Kia, discussing their advancements in V2G-capable vehicles.

The symposium underscored the pioneering role of the SCALE consortium in V2X development and the collaborative efforts required to overcome technical and regulatory hurdles, paving the way for a more resilient and sustainable energy system.
[Symposium: V2X (Vehicle to anything) • Events • ElaadNL]

# 9 Test Equipment

## 9.1 ElaadNL

To prepare the test facilities at ElaadNL to be ready to test the interoperability of V2G between EV and EVSE, but also between the EV, or EVSE, and the grid, certain laboratory equipment has been purchased. With this equipment it is possible to have full control over a V2G charging session, both in terms of power as well in communication. For example, it is possible to test a bidirectional EVSE without the use of an EV, by emulating the communication and the power flow of an EV. During these tests the grid AC power can also be controlled to emulate different grid situations, like voltage deviations or frequency shifts, to test the interoperability between the EVSE, EV and the grid. Also, the test equipment can be used to manipulate the communication between EV and EVSE to create non happy flow cases or to debug certain issues. To achieve all of this the following equipment has been purchased.

### 9.1.1 AC (grid) emulator

To emulate the AC side of the charging session, for example an AC charger or the connection of a DC charger to the grid, ElaadNL chose to invest in testing capabilities for testing up to 350 kW DC chargers. Therefore, AC emulation of up to 350kW was needed. The Keysight SL1200A has been selected as the AC emulator. A single unit can provide up to 90kW of power, therefor 4 units have been installed. The SL1200A is capable of creating a local (clean) grid independently of the normal grid. This makes it possible to measure distortions coming from the DUT. Apart from creating a clean grid, the SL1200A can also execute different kind of Power Quality scenario's (e.g. voltage changes, frequency changes or adding harmonics on the voltage). These scenarios can be performed independently on each phase, but also simultaneously on phases together.

*Figure 1: Keysight Sl1200A*

### 9.1.2 DC emulator

To emulate the DC side of the charging session, for example a DC charger or an EV battery, Elaad also chose to invest in a DC emulator. The Keysight SL1830A has been selected, of which a single unit can provide up to 180kW of power.

*Figure 2: Keysight SL1830A*

### 9.1.3 EV – EVSE Communication

To emulate and/or log the communication between EV and/or EVSE, the Keysight SL1047A & SL1550A have been selected. With the combination of these 2 products several use cases are possible. The first use case is a so-called Man in the Middle test (MitM), where the system is connected in between an EV and EVSE and acts as a logging system. This makes it possible to analyse the communication between the EV and EVSE. A second use case is a conformity test to the standards, specifically ISO 15118-20, where either an EV or EVSE is connected to the system. The SL1047A is capable of transporting the power to/from the DUT and the AC/DC emulators (which drain from or feedback power to the grid). This system is also capable of emulating the characteristics of an EV or EVSE, for example it is possible to emulate the SOC and stop charging when reaching full SOC. This feature can be useful during testing when switching between charging and discharging while respecting set minimal and maximal SOC values. A third use case is manipulating the communication to see how the DUT reacts when there is a mismatch (non-happy flow testing) or to debug in case of any issues.

*Figure 3: Keysight SL1047A & SL1550A*

### 9.1.4 Trialog/ElaadNL AC EVSE

Trialog and ElaadNL have developed together an AC charging station implementing ISO 15118 and OCPP. This station has been designed to be flexible to maximize interoperability, to test against different EV implementations and to adapt to upcoming charging technologies. The charging station records all the data exchanged with the vehicles and with the supervision system. This is a valuable input to identify potential issues in EV implementations and requirements in the standards that need to be clarified to enhance interoperability.


Within the SCALE project, this charging station has evolved to support bidirectional charging on both hardware and software levels.

On the hardware part, an anti-islanding module has been added to prevent power injection into the grid when it is not expected. For example, the grid operator is doing maintenance operation on the grid and there shall be no injection for safety reasons.

On the software part, both ISO 15118 and OCPP implementation have been upgraded. The support of ISO 15118-20 has been added to the station to test against AC bidirectional vehicles. The support of OCPP 2.1 has been added to control bidirectional charging from the CSMS and to demonstrate the usage of the recently published OCPP 2.1 specification.

### 9.1.5 Trialog EV ComboCS

Trialog has provided ElaadNL with their EV ComboCS to test the communication with charging stations.

The EV ComboCS is a simulation and testing device that simulates the behavior of an EV so it can test charging stations. The ComboCS device is also available in an EVSE version to test EV implementations. Both versions support:

- AC (1 phase, 3 phases) and DC charge
- Smart Charging
- V2G
- EIM and Plug&Charge (PnC) payment methods.

The EV ComboCS performs communication layer validation on different layers for different protocols:

- Physical layer (IEC 61851-1 for voltage and PWM)
- PLC layer (ISO 15118-3 & DIN 70121)
- Applicative layers (ISO 15118-2, ISO 15118-20 & DIN 70121)

To ease the testing, the ComboCS full version provides advanced charging simulation, interoperability tests, conformance tests (ISO 15118-4, DIN 71122) and other analysis tools. The objective is to analyze in detail the behavior of the systems under test and identify interoperability issues.

Charging sessions are done without any power transfer, but an interface exists to connect your own power bench to test under real conditions.

To adapt to the connectors present on a charging station, Trialog has developed a specific version of its EV ComboCS with an inlet as shown on picture below. So, the charging station can be plugged in directly without any adapter.


## 9.2 Enedis

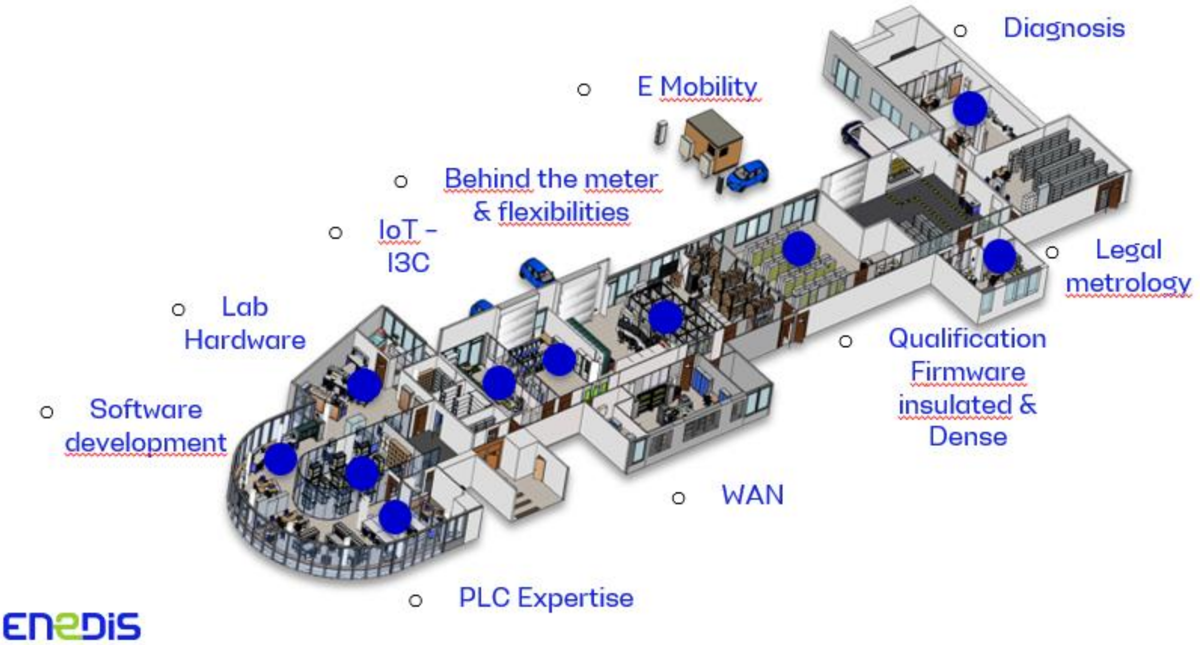
The main mission of Enedis Labs in Nanterre is to test and validate electrical equipment and technologies related to energy management. The lab focuses on evaluating devices such as smart meters, EV chargers, energy consumption management systems, and distribution grid equipment.

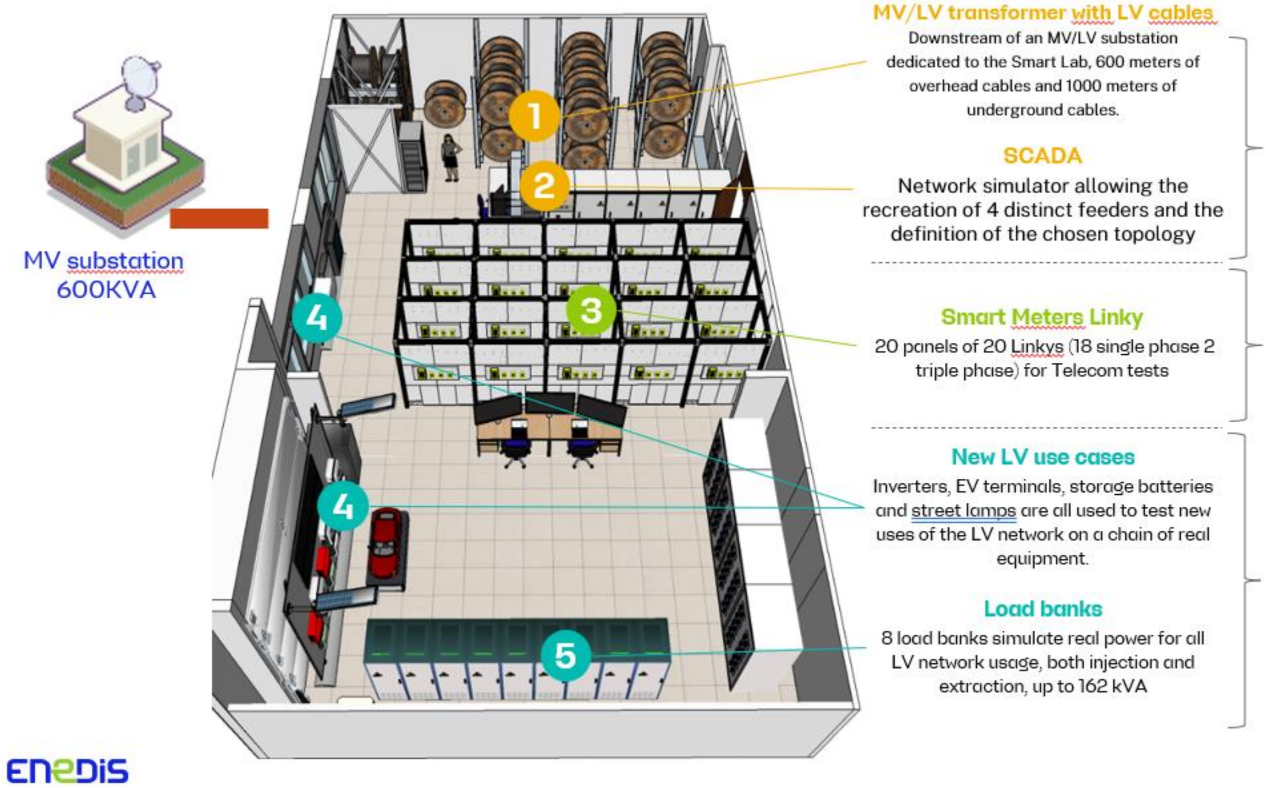
It allows for the simulation and testing of real-world scenarios to assess the performance, safety, and reliability of electrical installations. The goal is to ensure that new technologies meet the necessary standards and requirements before being deployed in the electricity network.

As the operator of the electricity distribution network, Enedis uses this center to improve network efficiency and support the development of innovative solutions for the energy transition. The lab plays a crucial role in optimizing electricity management, including generation, storage and news usages such as electric Mobility.

Additionally, it serves as a collaboration space for engineers, researchers, and companies who wish to test and validate their energy-related projects.

The main parts and activities of the lab are described in the figures below:




MV/LV transformer with LV cables
Downstream of an MV/LV substation dedicated to the Smart Lab, 600 meters of overhead cables and 1000 meters of underground cables.
SCADA
Network simulator allowing the recreation of 4 distinct feeders and the definition of the chosen topology
Smart Meters Linky
20 panels of 20 Linkys (18 single phase 2 triple phase) for Telecom tests
New LV use cases
Inverters, EV terminals, storage batteries and street lamps are all used to test new uses of the LV network on a chain of real equipment.
Load banks
8 load banks simulate real power for all LV network usage, both injection and extraction, up to 162 kVA
MV substation
600KVA
1
2
3
4
4
5
ENEDIS

### 9.2.1 Focus on E Mobility Labs

E Mobility labs has been triggered by the EV100 programme for electrification of Enedis Fleet (18 000 Vehicles). Currently 1/3 of the fleet has been electrified, and Regional Enedis operational agencies and well equipped with related chargers. The Labs was involved in assessing the chargers and the cars before purchasing EVs and the related chargers. The CPO solutions have been also tested to better supervise the charging services, such as smart charging options.



### 9.2.2 Latest installations – The DC 400 kW Comemso emulator

To better support Charging infrastructure deployment, Enedis Labs have invested in DC emulators, which allows to  speed up testing HPC without EVs and vise versa. The Man in the middle permits to validate the

COM between both sides (mainly ISO 15118). Below, are displayed some flyers for more information.

# Key techniques of the electric vehicle simulator

### Three high-power DC slots

With a power rating of 400 kW, our simulator will enable in-depth endurance tests on high-power charging points (HPC). This feature is designed to validate the resilience of the charging points while eliminating the need for real vehicles. We will also be able to provide two HPC slots of up to 400kW on real EVs.

### Simultaneous reloads

The simulator allows two recharges to be tested simultaneously, providing a full assessment of the terminal's performance in realistic scenarios.

### Discharge installation

A dumping station adapted to Enedis EVs is already on our site.

### AC tests

In addition to DC tests, our simulator will also enable AC tests to be carried out, thereby expanding our analysis and validation capacity.

### A wide range of vehicle models

With ten vehicle models available, our simulator offers maximum flexibility to meet a variety of use scenarios.

### Function maninthemiddle

An innovative feature of our simulator is the ability to carry out man-in-the-middle tests between the charging and the electric vehicle. This will enable us to simulate specific situations and guarantee the robustness of the systems under a variety of conditions.


**Tests in AC**

- ➢ AC testing, expanding our analysis and validation capabilities.

**DC Slot**

- ➢ 400 kW power
- ➢ Extensive endurance tests on HPC terminals
- ➢ Validation of terminal resilience
- ➢ 3 vehicle spaces

**10 models of EV**

- ➢ 10 EV models available
- ➢ Test 2 simultaneous recharges to evaluate terminal performance

ENEDIS

**Man-in-the-middle**

- Test exchanges between the terminal and the EV in man-in-the-middle mode.
- Guarantee system interoperability and robustness under a wide range of conditions.
- Discriminate poor software implementation in either the terminal or the EV.

**Vehicule-to-grid**

- Assess discharging impacts from EVs into the grid.
- Analyze exchanges as specified in ISO 15118.

## 9.3 Joint Research Centre

For Power Quality AC Bidirectional Charging, JRC uses a 50 kW bidirectional grid emulator with LISN and PQ measuring equipment. The LISN, an artificial network inserted into the supply line, measures conducted emissions and creates defined source impedance. JRC also has a climate chamber capable of testing from -30°C to +50°C.

In Power Quality DC Bidirectional Charging, JRC's capabilities will soon be upgraded to 500 kW capacity. Radiated emissions testing is limited, but JRC has an EMC testing chamber for assessing radiated and conducted RF emissions.

For Communication, JRC uses a Keysight CDS emulator and climate chambers.

### 9.3.1 VELA 9

VELA 9 is equipped with antennas that analyze electromagnetic emissions during driving, braking, or acceleration. It also allows testing the immunity of electric vehicles to external electrical or magnetic fields. These experimental setups are used for interoperability and integration research, primarily focused on smart grid systems and those connected to complex power transmission and distribution grids. The test lab also has the following capabilities:

- Modeling static and dynamic stimulation modules representative of the European power grid.
- Emulating and reproducing ICT, communication, and network systems applied to power grids.
- Real-time stimulation of power grids and hardware-in-the-loop testing (combining hardware and software).
- Visualizing data and scenarios.
- Interconnecting with other facilities, both within the JRC and externally.

VELA can conduct tests on various vehicle emissions, with outcomes influencing directives and evaluating new measurement techniques. They primarily focus on testing systems' interoperability according to standards and related to use cases and relevant structures. The test labs house power components, information and communication technologies, and advanced power systems.

# 10 Test Methods

## 10.1 General Overview

To test the V2G interoperability a general scope has been defined. The communication from CPO to a charger, which is usually through an CSMS and which will make use of either the OCPP 2.0.1 or the OCPP 2.1 protocol, has been tested. The communication from charging station to EV, which will make use of the ISO 15118-20 protocol, has been tested as well. At certain test locations, third party components have been added to the test set-up like a BESS.

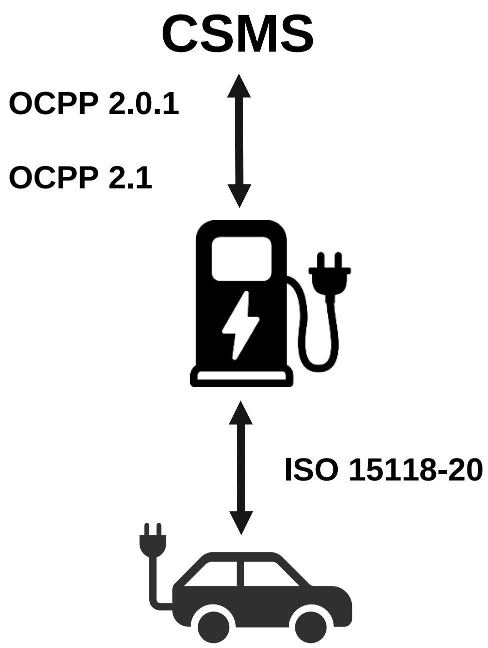



*Figure 4: Communication chain V2G interoperability testing*

Testing has been done not only with manufactured EVs and EVSEs, but also with lab equipment. This has been done to gather as much information as possible regarding the interoperability of V2G. The following test set ups have been used:

- EV to load (V2L)
- Laboratory equipment to laboratory equipment
- Laboratory equipment to EV
- EVSE to laboratory equipment
- EVSE to EV
- CSMS to laboratory equipment
- CSMS to EVSE
- Full chain test (e.g. CSMS to EVSE to EV)

When setting up a (dis)charging session with the DUT, it has been chosen to always start with charging to be sure everything is OK. When charging is successful the DUT will be switched to discharging. While discharging, the DUT has been requested to discharge on various discharging speeds. All communication has been monitored and analyzed.

If the DUT is tested on Power Quality while discharging the following scenarios have been tested:

- **Overvoltage** – Voltage rises from 230V linearly to 265V, this can be done phase independently.
- **Undervoltage** - Voltage drops from 230V linearly to 195V, this can be done phase independently.
- **Voltage sag** – Voltage drops from 230V to 161V (70%) for a period of 25 cycles (0,5s), after which the voltage is set back to 230V. This can be done phase independently.
- **Phase unbalance** – The voltage will phase independently be either increased or decreased (e.g. phase 1 230V, phase 2 190V & phase 3 240V)
- **Overfrequency** – Frequency is increased from 50Hz linearly to 52Hz and linearly back to 50Hz
- **Underfrequency** - Frequency is decreased from 50Hz linearly to 47Hz and linearly back to 50Hz
- **Added Harmonics** – Several Even or Odd Harmonics and Interharmonics will be added on the voltage

The following standards have been used during testing Power Quality: EN 50160, EN 50549-1, IEC 61000 series.

This chapter will describe how previously mentioned test equipment and test set ups have been used during testing.

## 10.2 ElaadNL

### 10.2.1 V2G EVSE – EV Communication

#### *10.2.1.1 Laboratory equipment to laboratory equipment*

*Laboratory equipment (AC) to Laboratory equipment (AC)*

The laboratory equipment at ElaadNL is capable of emulating both EV and EVSE. The set up below emulates an AC EVSE and AC EV. It is possible to manipulate messages to create non happy flows. This set-up is mainly used during the development of the V2G interoperability testcases. During this set it is possible to have no active power flow.

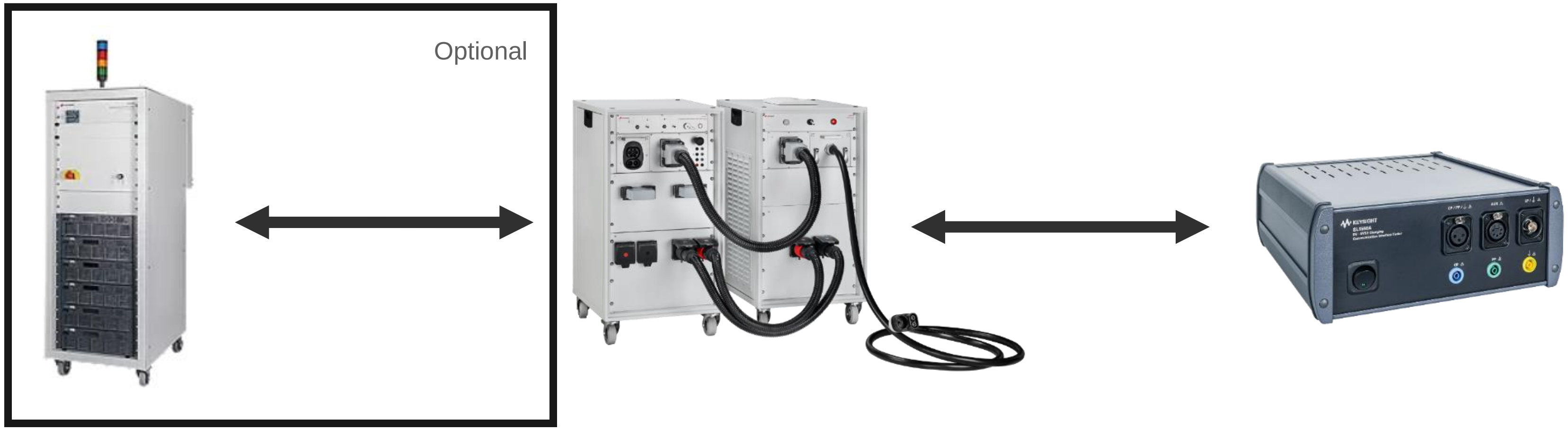
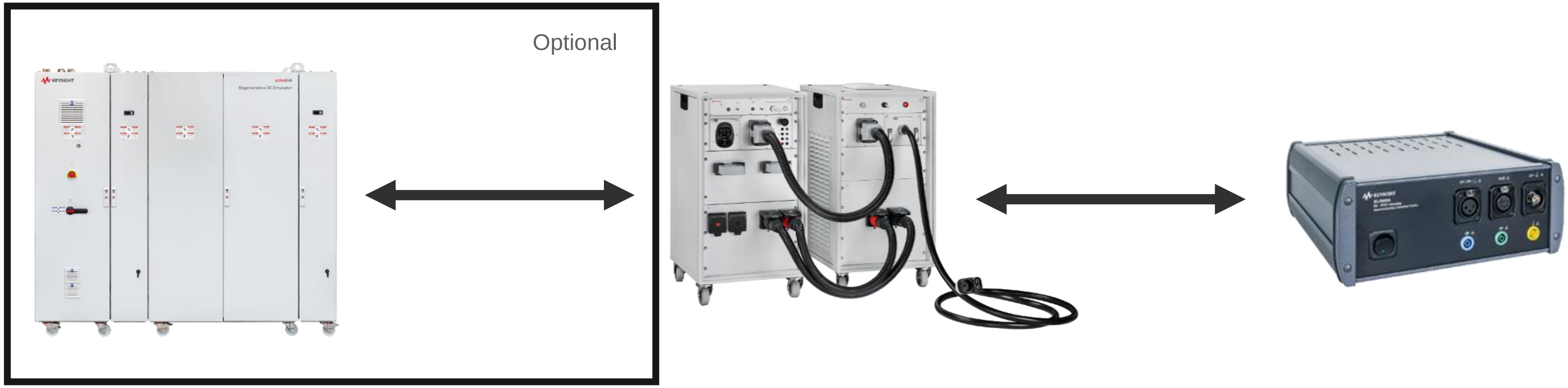



*Figure 5: Laboratory equipment (AC) to laboratory (AC) equipment test set-up*

*Laboratory equipment (DC) to Laboratory equipment (DC)*

The laboratory equipment at ElaadNL is capable of emulating both EV and EVSE. The set up below emulates a DC EVSE and DC EV. It is possible to manipulate messages to create non happy flows. This set-up is mainly used during the development of the V2G interoperability testcases. During this set it is possible to have no active power flow.



*Laboratory equipment (AC) to Trialog EV ComboCS emulator*

During this set-up the laboratory equipment emulates an AC EV or EVSE while the Trialog ComboCS simulates an AC EVSE or EV. This set up can be used to check if a certain testcase works on different kinds of implementations of a protocol, for example the ISO 15118-20 protocol. At first, a breakout box has been created to connect the Keysight equipment to the EV ComboCS because the EV ComboCS did not have an inlet to connect a charging cable. During the project, the ComboCS design has been improved to include an inlet. Now the Keysight can be directly connected without the breakout box.

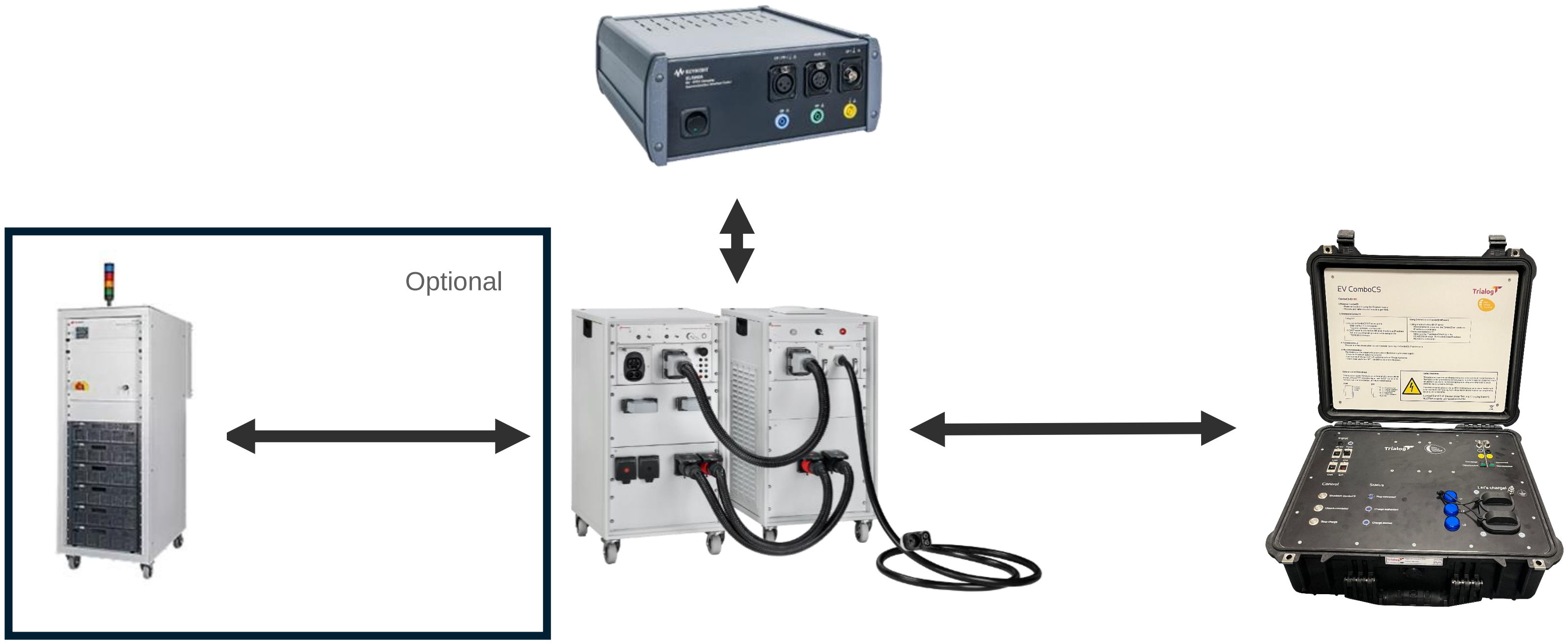



*Figure 6: Laboratory equipment (AC) to Trialog EV Combo CS emulator test set-up*

*Laboratory equipment (DC) to Trialog EV Combo CS emulator*

During this set-up the laboratory equipment emulates a DC EV or EVSE while the Trialog ComboCS emulates a DC EVSE or EV. Note: To emulate a power flow the requested DC current was set to 0A (No active power flow). This set up can be used to check if a certain testcase works on different implementations of protocols, for example the ISO 15118-20 protocol. At first, a breakout box has been created to connect the Keysight equipment to the EV ComboCS because the EV ComboCS did not have an inlet to connect a charging cable. During the project, the ComboCS design has been improved to include an inlet. Now the Keysight can be directly connected without the breakout box.

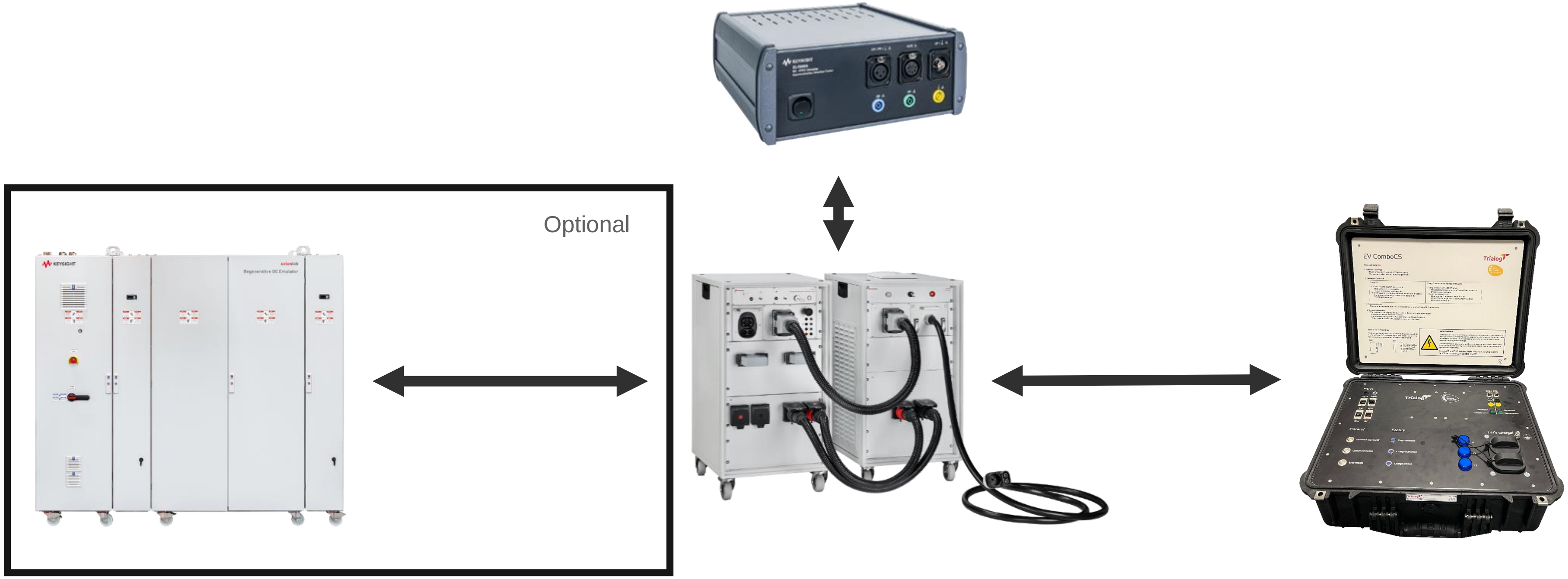



*Figure 7: Laboratory equipment (DC) to Trialog EV Combo CS emulator test set-up*

### 10.2.1.2 Laboratory equipment to EV

During this set up the laboratory equipment emulates an EVSE while an EV is connected. This can be done both on AC and on DC. With this test set up it is possible to test various charging scenarios including charging/discharging but also power quality during charging/discharging in case of an AC session.

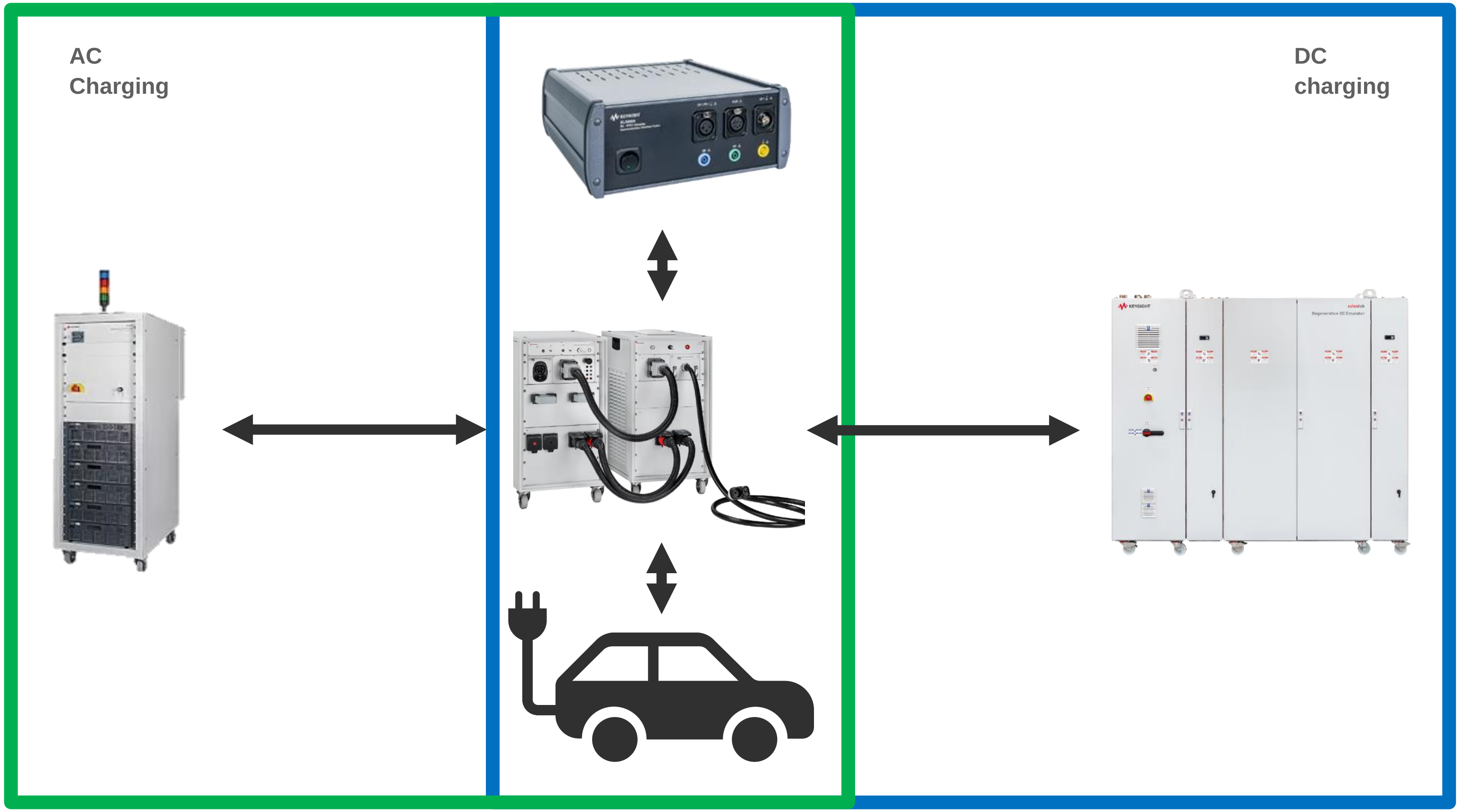



Figure 8: Laboratory equipment (AC/DC) to EV test set-up

### 10.2.1.3 EVSE to Laboratory equipment

During this set up the laboratory equipment emulates an EV while an EVSE is connected. This can be done both on AC and on DC. With this test set up it is possible to test various charging scenarios including charging/discharging but also power quality during charging/discharging in cause of a DC session.

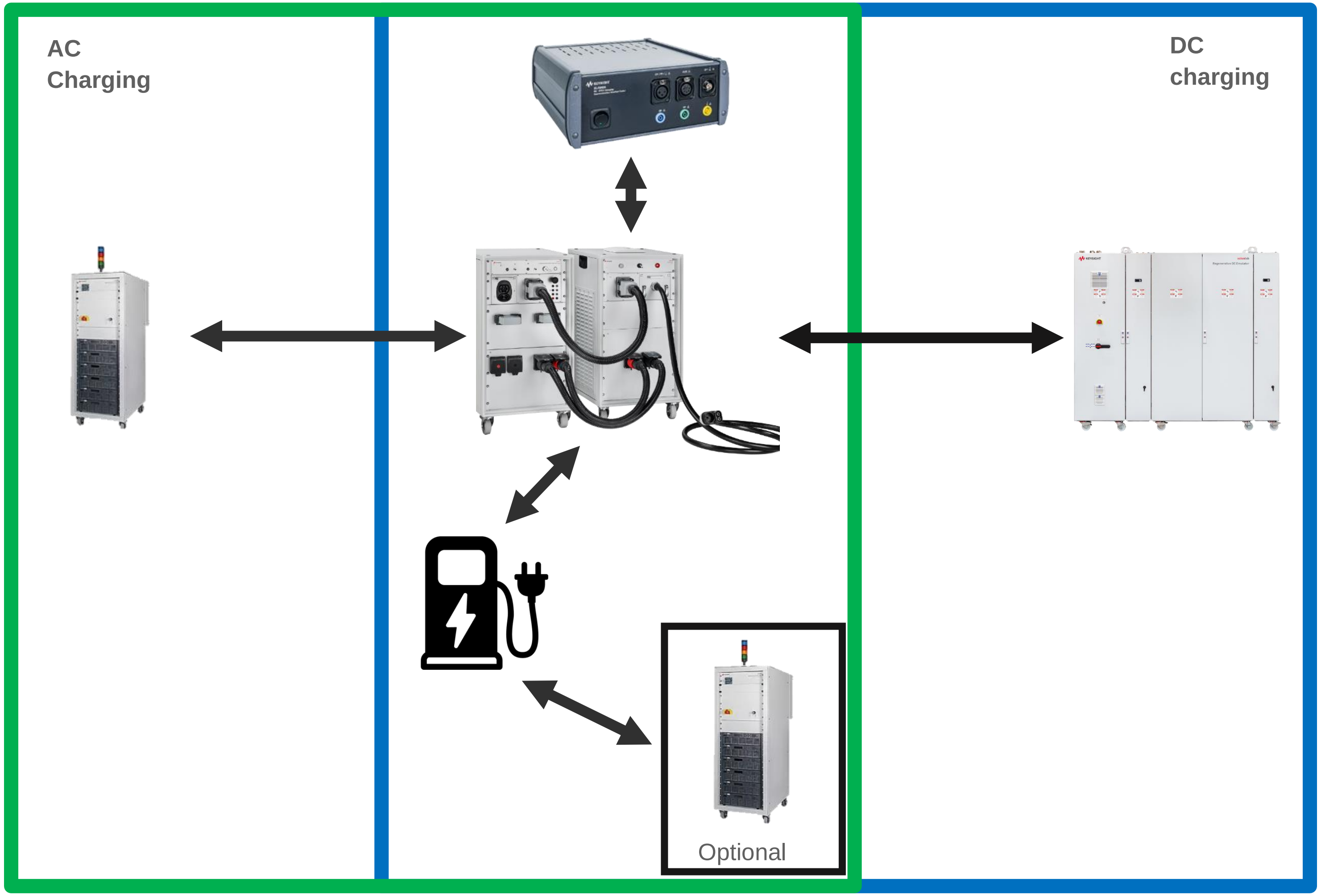



Figure 9: EVSE to laboratory equipment (AC/DC)

### 10.2.1.4 EVSE to Trialog ComboCS EV

In this set up an EVSE is directly, with the help of a breakout box, connected to the Trialog ComboCS. Due to the compactness of the ComboCS, this set-up can be used to test bigger DC EVSEs without having to transport the EVSE. This set-up has been mainly used to study and learn how the 15118-20 protocol operates, for the development of the V2G interoperability testcases and for the development of the software of the tested EVSE (together with the EVSE manufacturer).


*Figure 10: EVSE to Trailog ComboCS*

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#### 10.2.1.5 EVSE to EV

During this set up an EV will be connected to an EVSE. The CDS of Keysight will be placed in between to capture the communication between the EV and EVSE, which is called an MitM set up. With this set up it is also possible to perform Power Quality scenarios as the charging station can be supplied by a grid emulator.

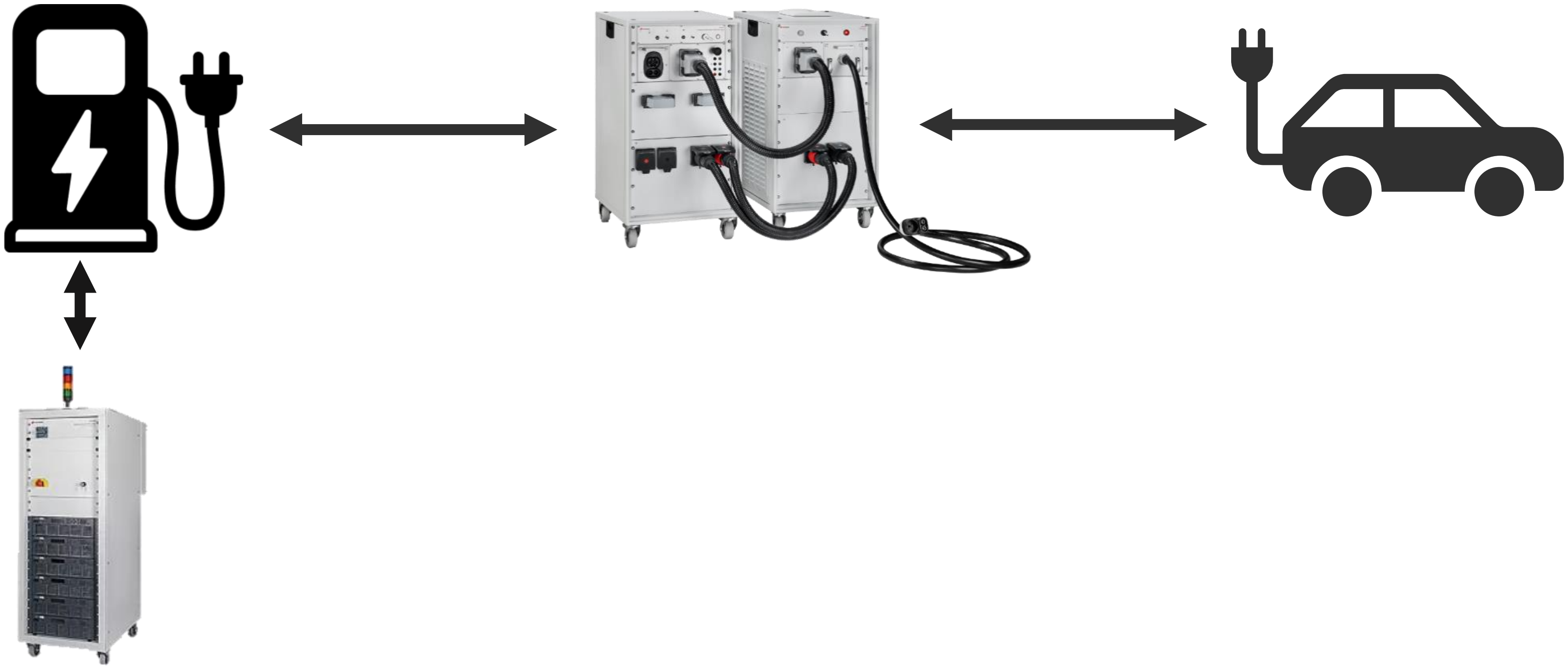

*Figure 11: EVSE to EV test set-up*

### 10.2.2 V2G CSMS – EVSE Communication

#### *10.2.2.1 CSMS to laboratory equipment*

During this set up a connection will be established between a CSMS and the laboratory equipment. This set up is mainly used to check if it is possible to send the correct messages from the CSMS to the laboratory equipment. This set up is mostly used without an active power flow.

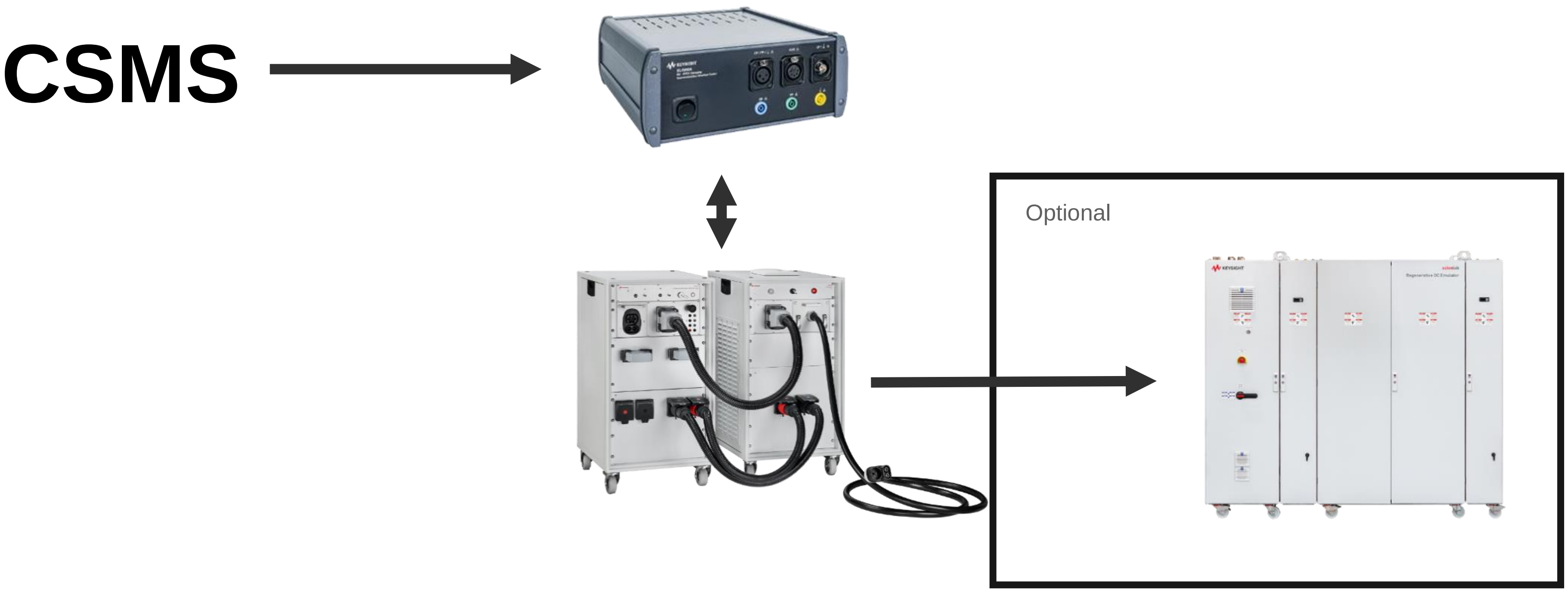


*Figure 12: CPO to laboratory equipment test set-up*

#### 10.2.2.2 CSMS to EVSE

During this set up a connection will be established between a CSMS and an EVSE. This set up can be used to check if the EVSE is correctly responding on messages from the CSMS. It is also possible to connect the EVSE to the laboratory equipment to see if the EVSE will execute commands coming from the CSMS correctly.

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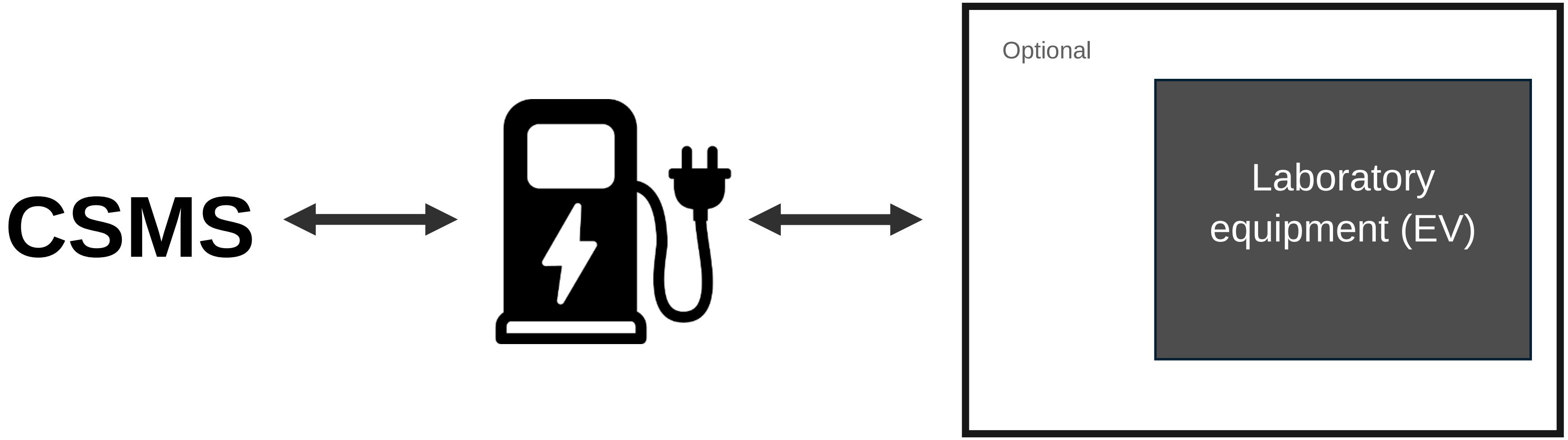



*Figure 13: CPO to EVSE test set-up*

### 10.2.2.3 CSMS to EVSE to EV

During this set up a CSMS will be connected to an EVSE, which will be connected to an EV. This is also called a full chain test. In this set up the CSMS will send a command to the EVSE, which in turn will communicate the necessary information to the EV. If possible, the communication is captured for analysis with laboratory equipment.

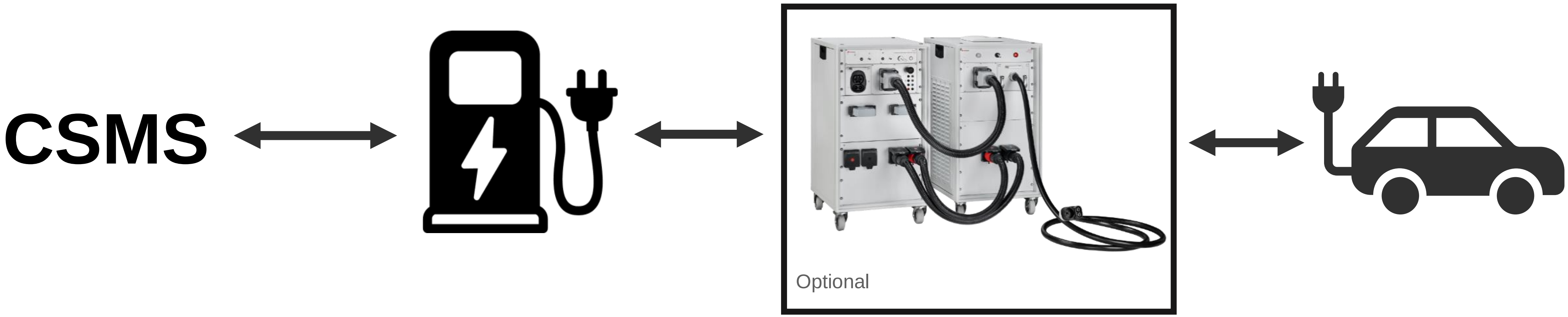
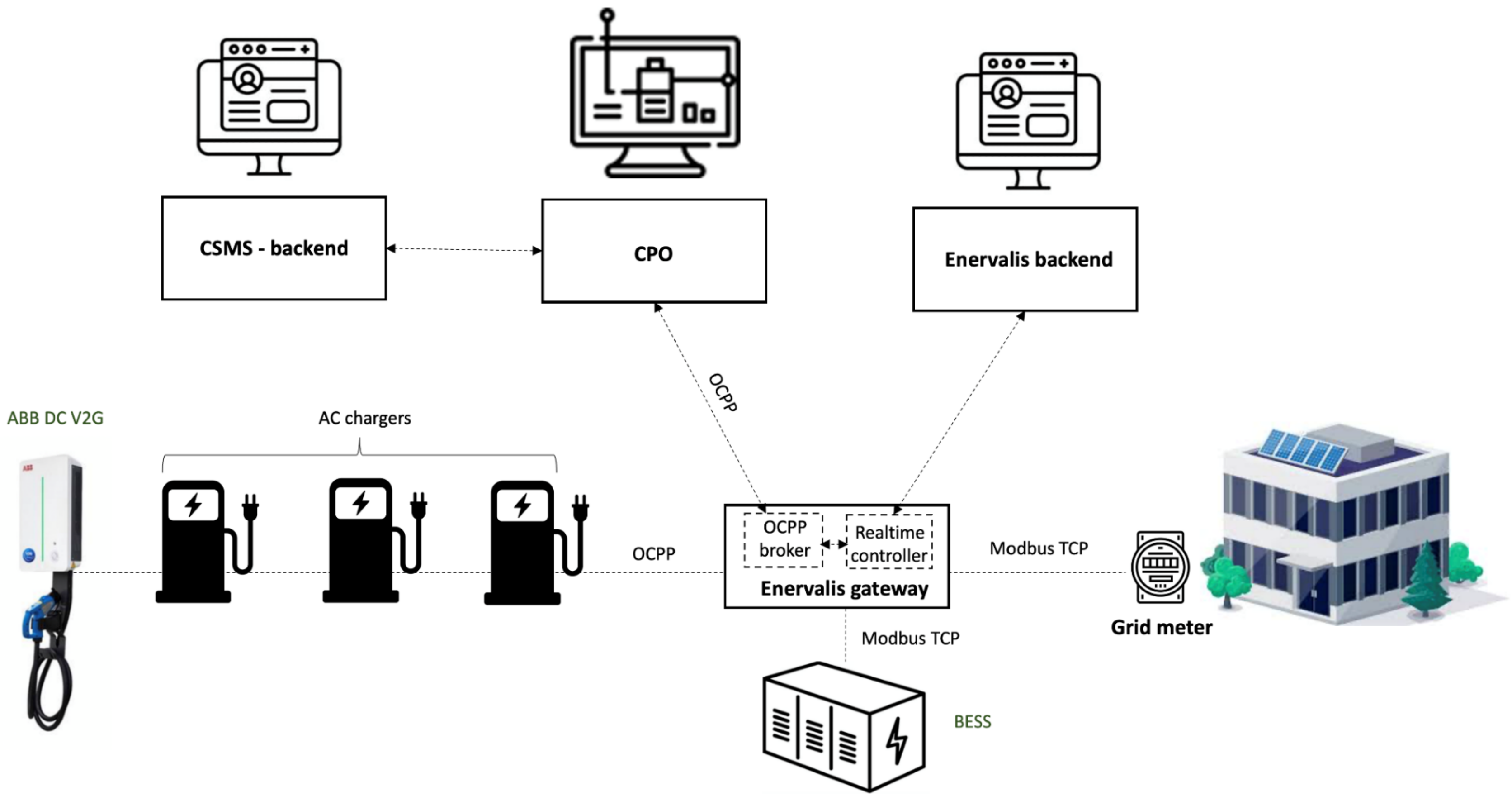



*Figure 14: Full chain test*

## 10.3 Enervalis

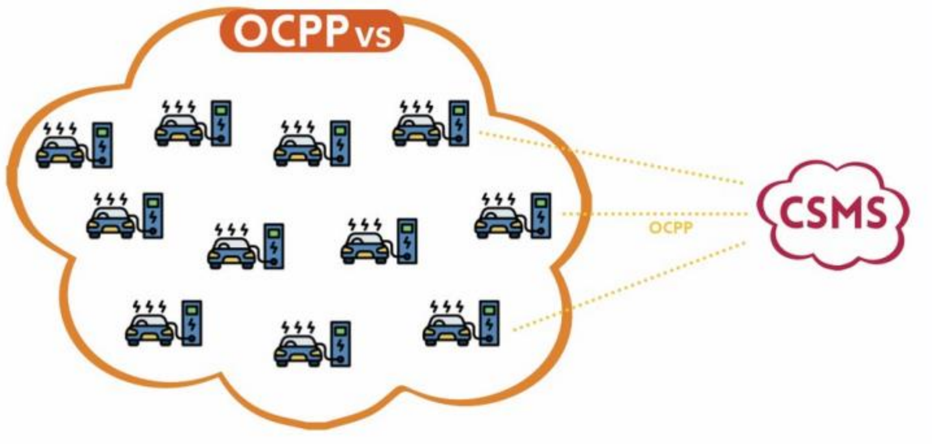



The figure above shows the smartcharging and V2G architecture for the VDL and 3 Hungarian use cases. The core of the setup is the ABB Terra Gateway Pro. This EMS (energy management system) device controls all the assets on site and acts like an OCPP broker between the charger and the

CPO backend. In this way all charging sessions can be “intercepted” and the TGP gets a sight on all charging sessions which are going on at the location. This information is used for optimizing the energy flows onsite and ensure an optimal scenario.

## 10.4 Trialog

To ease smart charging and bidirectional charging testing, Trialog has deployed its solution OCPPvs (OCPP virtual stations). OCPP virtual simulator is a cloud-based service for CSMS and EMS validation. It provides access to cloud based virtual charging stations for scalability and stress testing of OCPP 1.6 or OCPP 2.0.1 implementations. Within SCALE, OCPP 2.1 has been added to perform testing with CSMS from the partners.




There is ongoing discussion with different partners (Current and Clem) in the project to test their CSMS against OCPPvs in the upcoming months. There is no test result or lesson learned that can be shared when this document is being written. They will be shared with the consortium before the end of the project.

# 11 Test Results

## 11.1 EV – EVSE Communication

### 11.1.1 Laboratory equipment to laboratory equipment

After installation and commissioning of the laboratory equipment at the Elaad Testlab it was possible to start preparing and developing testcases to be ready for the first delivery of products within the project.

Because the ISO 15118-20 protocol is a complex protocol, a draft was published at the start of the project, it implemented at a step-by-step approach. To see how the DUT responds a first connection is made using the ISO15118-2 protocol. Later a connection is set up with the ISO 15118-20 protocol to see if discharging is possible.

During the first testing days of WP2.5 at the Elaad Testlab a connection was set up between the laboratory equipment, both set on AC charging. It did not take much effort connecting both emulated EV and EVSE on the ISO 15118-2 protocol. With this set-up it was possible to charge on various charging currents. The next step was emulating a DC EVSE and EV, again on ISO 15118-2. This took more effort to get all the parameters right due to the power flow, but eventually it was possible to emulate a charging session (without active power flow).

Since everything was working on the ISO 15118-2 protocol, it was time to step over to the ISO 15118-20 protocol. This was more challenging. To start with, it is mandatory to have an encrypted connection using TLS on the ISO 15118-20, which is optional on ISO 15118-2. It is a quite complex configuration which is prone to error. To continue with the development of the testcases, methods have been searched to (temporarily) disable TLS and connect only on TCP.

When the first versions of the Trialog ComboCS software stack, both EV and EVSE, were delivered the first real interoperability testing could start. The delivered software was still in development phase, therefore it took some effort and help of Trialog to get everything up and running. Eventually it was possible to connect the Trialog devices to the laboratory equipment and have a successful transaction. Both EV and EVSE could run the ISO 15118-20 protocol (with TLS disabled), and it was possible to charge and discharge on both AC and DC for the EV and on AC for the EVSE. It was even possible to have a successful first test applying grid codes from the (ComboCS) EVSE to the EV done at the Elaad Testlab together with Trialog. While one of the AC emulators of Keysight was supplying the EVSE with 240V, the EVSE responded to this voltage by reducing the maximum active power. This has been tested with both the Trialog ComboCS EV as well as the Keysight equipment set to an EV.

The grid codes have been configured on the charging station using OCPP 2.1 to demonstrate the features present in this new version of OCPP. It was also the occasion to validate the use cases defined in OCPP 2.1 to configure different types of grid codes.

### 11.1.2 Laboratory equipment to EV

The next step within the project was the delivery of EVs to the test labs. This was the first time testing could be done against a product of which almost no control was available, so-called black box testing. Unfortunately, EV1 was already delivered before the laboratory equipment was installed. Therefore, no interoperability testing could be done against EV1.

After the arrival of EV2 the first testing of an EV against the laboratory equipment could start. Again, a first charging session is done on ISO 15118-2 to see if any abnormalities can be noted. For EV2, no problems have been found setting up a charging session on ISO 15118-2. Connecting to the vehicle using ISO

15118-20 could become a problem since no certificates were available at the testlab to set up a TLS connection. At the time of testing, it was not known if EV2 would accept an ISO 15118-20 connection without TLS. Nevertheless, an attempt was made to connect without TLS. For AC, this was not possible. The vehicle would stop negotiation and would not accept an AC connection. For DC it was possible to set up a connection, but unfortunately it was only possible to charge. When setting the EV to discharge the laboratory equipment saw a deviation from the standard and stopped the transaction. It was not clear if the tested software version was based on the final version of ISO 15118-20 or on the Committee draft version (which could explain deviations).

### 11.1.3 EVSE to Laboratory equipment

Parallel to the installation of the laboratory equipment and testing of the EVs, EVSEs also have been delivered for testing. Unfortunately, the first (AC) EVSE (EVSE1) was already delivered for testing while the laboratory equipment was not fully operational yet, therefore it was not possible to test this system against the laboratory equipment.

EVSE2 was a DC EVSE which was already at the Elaad Testlab facility for some time, but the software was still under development. During the Scale project engineers from the manufacturer came to test their current software version together with engineers from the Elaad Testlab several times. While the laboratory equipment at the Elaad Testlab was still under construction, Trialog already provided a testable version of the ComboCS. EVSE2 has been tested several times against the ComboCS with both EVSE2 and the ComboCS still under development. Nevertheless, it was eventually possible to have a transaction on 15118-20, with TLS disabled. Setting the EVSE to discharge was unfortunately still not possible.

EVSE3 & EVSE4 were also both AC chargers. These were delivered after the installation of the laboratory equipment was finished. For one of these EVSEs the Elaad Testlab unfortunately did not have access to the backend therefore testing it with the laboratory equipment was very difficult. The other EVSE, in this case the WDS charging station, has been tested together with the manufacturer against the laboratory equipment. For ElaadNL this was the first charging demonstration with an EVSE based on the final version of the ISO15118-20 protocol.

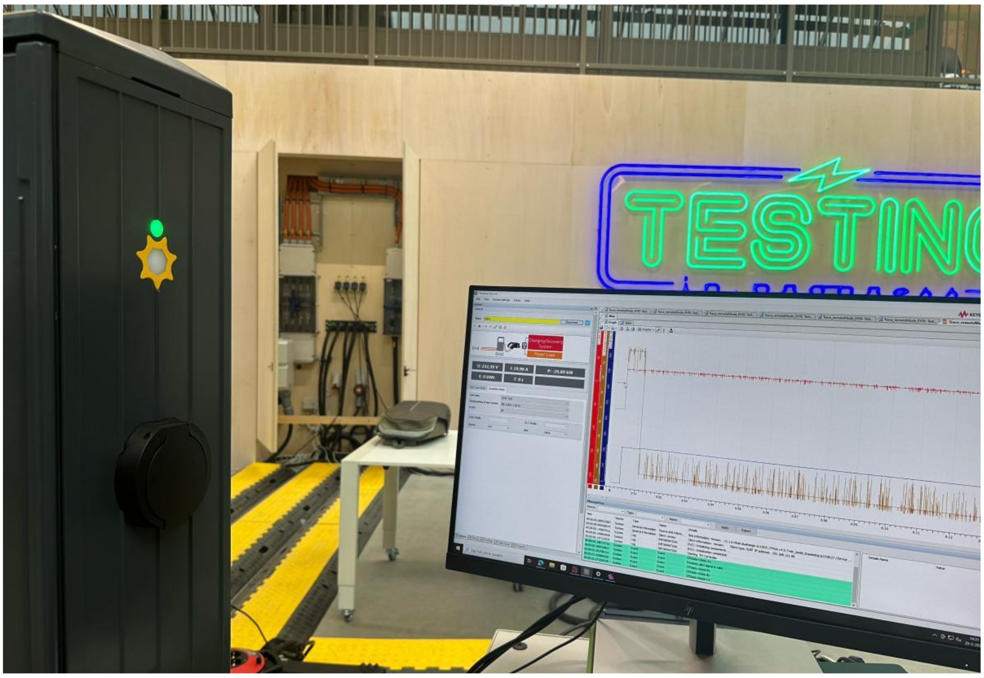


*Figure 15: First AC-bidirectional charging demonstration at the Testing Lab of ElaadNL, based on the final version of the ISO15118-20 protocol*

The last EVSE delivered at the Elaad Testlab was a DC EVSE (EVSE5). Again, a first check has been done using the ISO 15118-2 protocol. Because no issues were found using the ISO 15118-2 protocol, the EVSE was ready to be tested on ISO 15118-20. Since the manufacturer made it possible to disable TLS, a successful connection was made. Both charging and discharging was possible on the laboratory equipment.

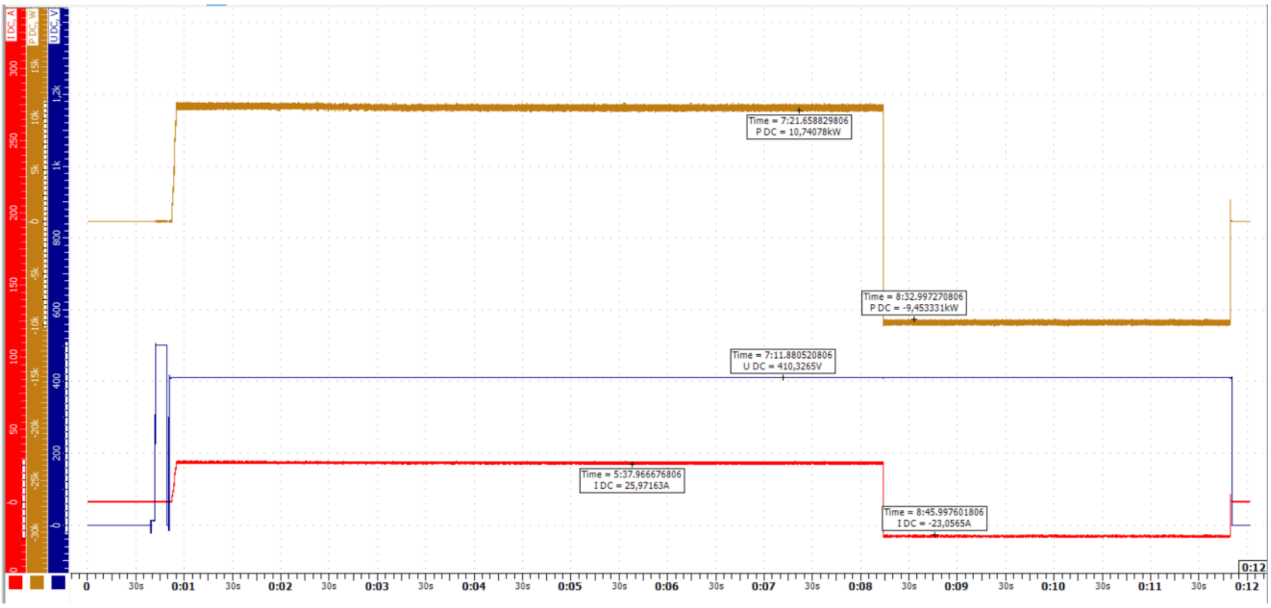



*Figure 16: EVSE to laboratory equipment: Charging at 11kW and discharging at 10kW*

EVSE5 has also been tested against the Trialog ComboCS with TLS disabled. The EVSE was able to go into charging mode and into discharging mode, but with no active power flow (which is not possible with this set up).

### 11.1.4 EVSE to EV

Testing the V2G interoperability of an EVSE to an EV is the most interesting part within the project, since this reflects what can happen in the field the most.

The first EVSE to EV test was performed using EV1 and EVSE1. With this combination it was possible to charge and discharge, but only within a dedicated session. This means the session was either charging or discharging, switching within the session was not possible. Unfortunately, both EVSE1 and EV1 were not available for a longer period therefor both could not be tested against other EVs or EVSEs.

Both EVSE2 (AC) and EVSE3 (AC) were planned to be tested simultaneously with an EV (EV2 and EV3), but unfortunately EVSE2 was already shipped back at the time EV3 arrived. Therefore, it was not possible to test the interoperability between EVSE2 and EV3. Testing EV2 with supplied EVSE2 was not straightforward due to the testlab not having access to the CSMS which EVSE2 was connected to. It was eventually possible to perform and log a successful V2G session with the help of the EVSE supplier. Unfortunately, it was not possible to test EV2 with EVSE3 due to EVSE3 using a certain PKI chain to set up a connection on ISO 15118-20 with TLS which was not yet supported by EV2. Taking that into account, testing EVSE2 with EV3 should theoretically also not work, since EV3 uses the same PKI chain as EVSE3.

However, EVSE4 (DC) was delivered on time to be tested with an EV. Unfortunately, it was not possible to connect to ISO 15118-20 due to the vehicle selecting a different protocol. Nevertheless, it was still possible to discharge this EV when sending a discharging profile to the EVSE with EVSE4.

Note: When testing an EV against an EVSE it is not possible to select the communication protocol. The EV is in the lead of selecting any communication protocol the EVSE can offer. This means if the EVSE offers any other communication protocol than ISO 15118-20 and the EV has set a higher priority on such communication protocol then ISO 15118-20 will not be selected in that charging session.

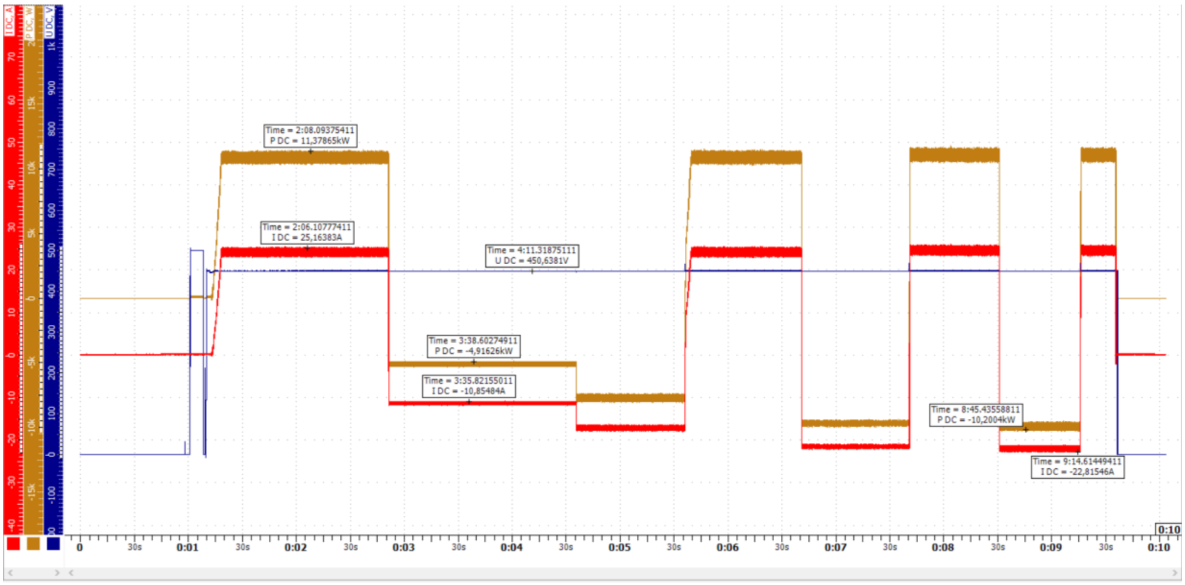



*Figure 17: EVSE to EV: Charging/Discharging on various speeds*

Picture below has been received from WeDriveSolar when they have been testing V2G hardware together with an EV manufacturer at their R&D centre. According to WeDriveSolar they successfully tested the onboard charger together with their EVSE.

*Figure 18: Successful V2G charging test WDS charger with EV onboard charger at R&D centre*

### 11.1.5 Conclusion

After all the testing the conclusion can be made that a lot of work has been done into enabling V2G functionalities into EVs and EVSEs. Progress has been made comparing the beginning of the project to the end. The project started with a vehicle to load configuration, where a vehicle could supply a single household equipment. Later in the project a dedicated EV and EVSE combination was tested and at the end of the project a non-dedicated EV and EVSE combination has been successfully discharging. The tested EVs and EVSEs are all capable of performing V2G, although sometimes with a custom implementation. Looking at V2G interoperability level this means that it is still on low and there is room for improvement.

### 11.1.6 Recommendation

To start with, it is highly recommended to keep developing as the development is on the right track. To have a high level of interoperability regarding V2G it is recommended to follow the (final) published standards instead of releasing an implementation based on a committee draft. Developing a dedicated EVSE and EV combination is also not recommended, since this is not interoperable at all.

Next to the communication standards, it is recommended looking into the development and implementations of grid codes since this will be necessary for stable V2G sessions, both for EVs and EVSEs. For many manufacturers it is not clear what exactly needs to be certified. For example, is the EVSE or the EV responsible for the right grid codes during an AC discharging session? Or do both need certification? It is recommended to have a clear roadmap.

The Testlabs will continue to test the interoperability of V2G implementations and manufacturers are recommended to come and test their products at the Testlabs.

## 11.2 CSMS/EMS – EVSE Communication

Next to testing the communication protocol of ISO 15118-20 between EVSE and EV, the communication protocol OCPP 2.0.1 between CSMS and EVSE has also been tested.

### 11.2.1 CSMS to laboratory equipment

At the Elaad Testlab only their regular used CSMS was available. With this backend it was able to successfully send a charging profile to the laboratory equipment to either set to charge or discharge. Together with Trialog another test has been performed using the recently released OCPP 2.1 instead of 2.0.1. During this test it was possible to send grid codes from a CSMS (which was not a Scale partner) to the EVSE. These grid codes have been successfully received at the EVSE and the EVSE did respond on voltage fluctuations afterwards.

### 11.2.2 CSMS to EVSE

While the laboratory equipment was still being installed, EVSE1 could be tested against the CPO (backend) of the Elaad Testlab. With the help of the manufacturer, it was possible to connect the EVSE to the backend using OCPP 2.0.1. It was possible to set the charger in charging mode or discharging mode and it was also possible to send charging profiles to change the charging and discharging speed. Yet there was still some room for improvement looking at interoperability since the above behavior was not completely triggered by using the standards. This is probably due to the development of EVSE1 already started when only draft versions of the standard were available. EVSE1 was also integrated in the backend of LastMileSolutions. The smart and bidirectional charging sessions using OCPP2.0.1 were here also not fully successful.

EVSE2 and EVSE3 have only been tested by the supplied CSMS, therefore no interoperability results have been gathered using these EVSEs.

EVSE4 has been tested against the backend of the Elaad Testlab. The configuration has been done by the manufacturer without any problems. Therefore, the EVSE was ready for testing shortly after delivery. The EVSE was connected on OCPP 1.6 instead of OCPP 2.0.1, yet it was still possible to successfully test the V2G interoperability. EVSE4 was able to charge and discharge by sending charging profiles through the backend.


```
"chargingRateUnit": "W",
"chargingSchedulePeriod": [
  {
    "startPeriod": 0,
    "limit": -10000
  }
```

```
{
  "status": "Accepted"
}
```


### 11.2.3 Conclusion

After all the testing the conclusion can be made that it was possible to have a discharging session with all the tested EVSEs, although sometimes with a workaround. Some EVSEs did not yet support OCPP 2.0.1, while others had their own (unique) implementation to communicate charging profiles between CSMS and EVSE, but some also followed OCPP 2.0.1 correctly. It can be seen that those who follow the standards have no issues in enabling a discharge session, indicating the importance of following the standards.

### 11.2.4 Recommendation

Within the Scale project all EVSEs have been tested against OCPP 2.0.1. To have a fully operational, grid code applicable system, OCPP 2.1 is needed. Focus of implementing OCPP 2.1 is recommended to be able to fully communicate all necessary parameters for safely performing a discharging session. This will benefit the mass market deployment of V2G. The Testlabs will continue to focus on testing OCPP 2.1 implementations and it is recommended to test implementations together with the Testlabs.

## 11.3 Interoperability results with the grid

V2G interoperability is not only communication, but also interoperability to the grid. Therefor the Elaad Testlab also took some effort to look at the Power Quality of EVs and EVSEs while discharging to the grid. Certain scenarios have been created with the grid emulator while powering the EVSE. Such scenarios are Overvoltage, Undervoltage, Voltage dips, Overfrequency, Underfrequency and added harmonics.

### 11.3.1 EVSE Power Quality

It has been noted that there are only minor differences in the Power Quality behavior of a certain EVSE between charging and discharging. For example: In pictures below, it can be seen that the general behavior during an Overvoltage on phase 1 is the same, but during charging Phase 3 (green) seems to drop a bit more compared to discharging and Phase 1 (red) and 2 (blue) seem to drift together, while the voltage is increasing during charging, and Phase 1 and 2 are drifting apart, while the voltage is increasing during discharging.

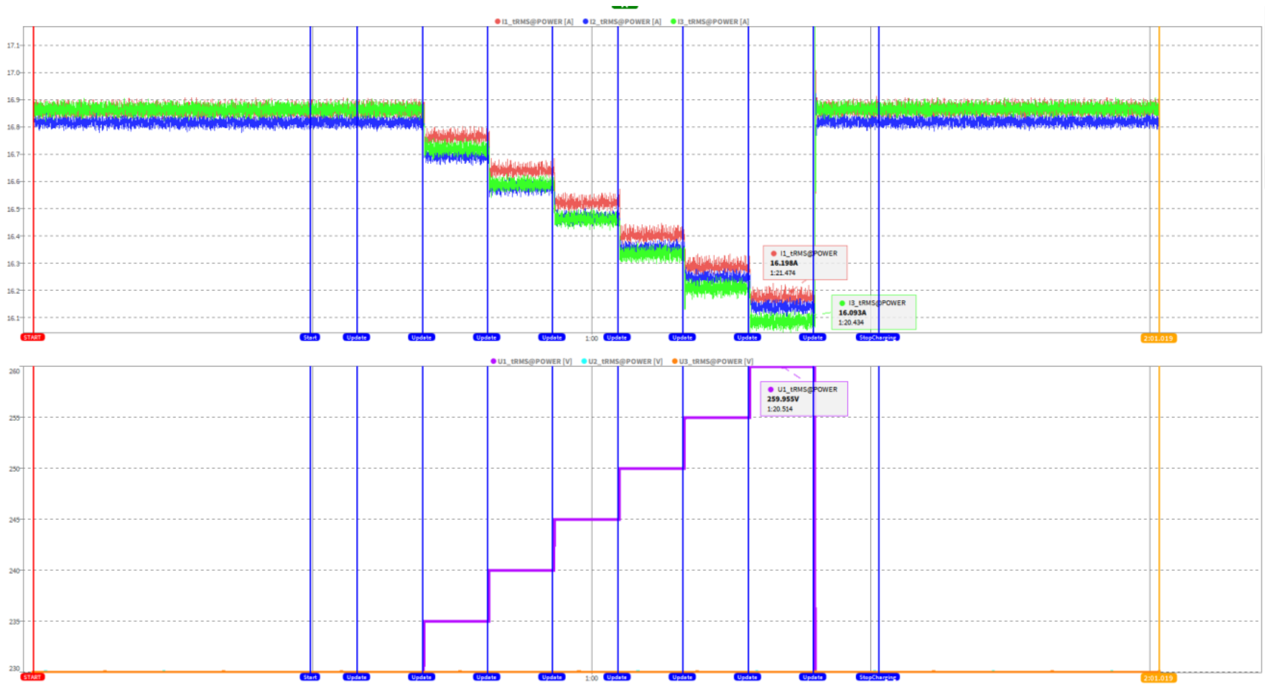


*Figure 19: Overvoltage on phase 1 during charging*

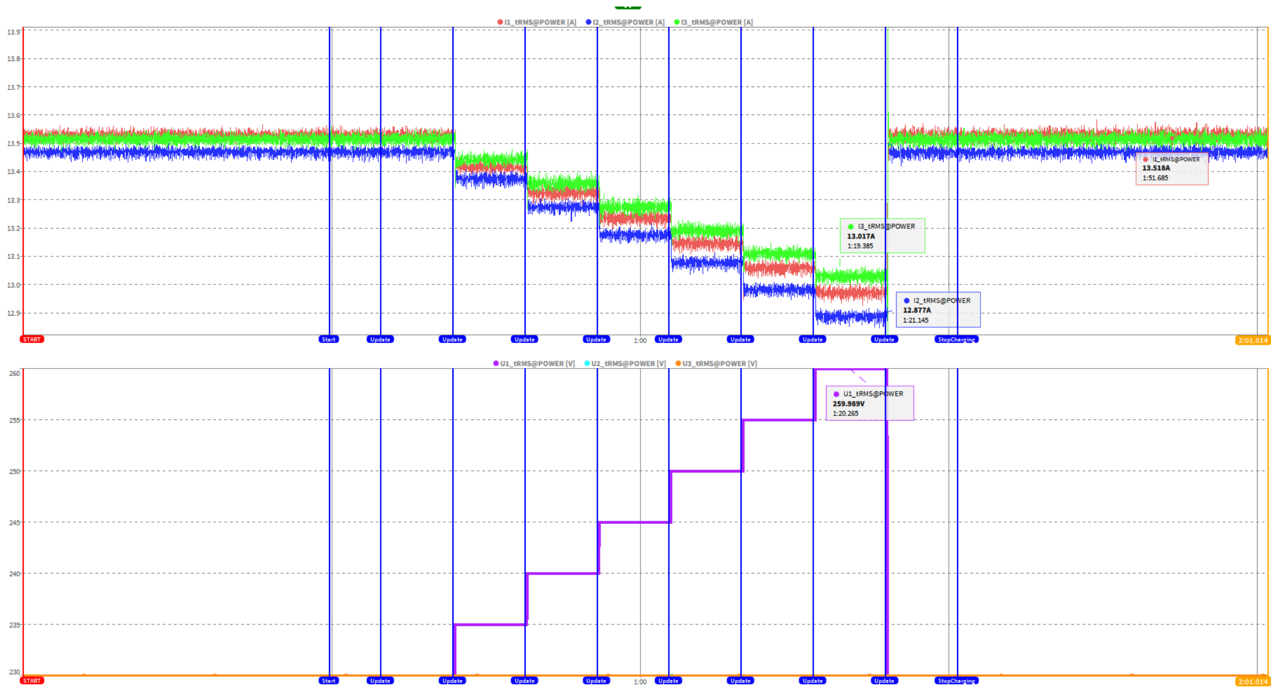



*Figure 20: Overvoltage on phase 1 during discharging*

### 11.3.2 EV Power Quality

The Power Quality results regarding EVs while discharging back to the grid are similar to EVSEs. There are only minor differences measured during discharging compared to charging. The general behavior is the same with some variations on how each phase is influenced by the Power Quality scenario.

### 11.3.3 Conclusion

Overall seen, the Power Quality behavior of EVs and EVSEs while discharging is similar to charging. This does not mean that everything is OK since there is still room for improvement, even on charging.

### 11.3.4 Recommendation

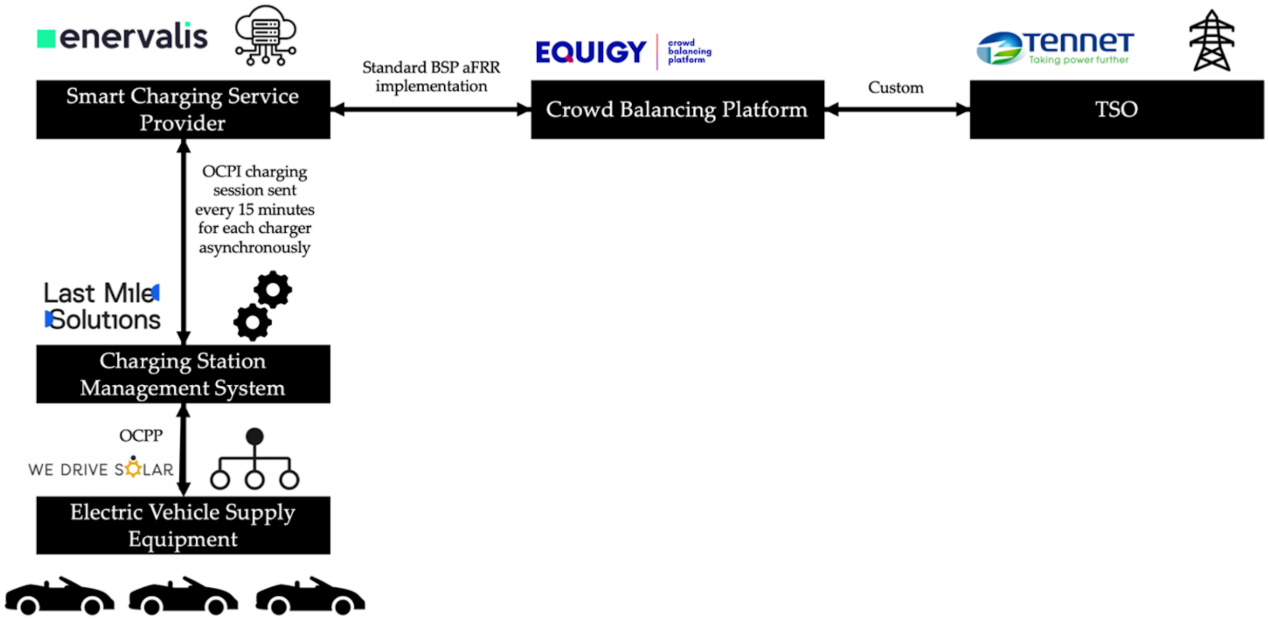
Since there is still room for improvement it shows the importance of keeping testing the developments of EVs and EVSEs. Power quality is closely connected to grid codes. It is recommended to test together with the Testlabs to learn what can still be improved in the current product or to learn for future development. It is important to be able to comply with the gridcodes while discharging, therefor it is recommended to implement OCPP 2.1.

## 11.4 aFRR grid services

### 11.4.1 aFRR test-setup

The conducted aFRR tests within the SCALE project play a critical role in demonstrating the technical feasibility and reliability of electric vehicles (EVs) as flexible assets for grid balancing. This Proof of Concept specifically focused on utilizing a fleet of EV chargers managed by We Drive Solar in Utrecht. During these tests, the response of the chargers to automatic Frequency Restoration Reserve (aFRR) activation signals from Enervalis via the Equigy platform was evaluated, including data recording and real-time visualization through Grafana.

The test setup involved precise protocol execution where Enervalis sent activation signals to the chargers, aimed at reducing their charging capacity without vehicle-to-grid (V2G) discharging. This approach evaluated the chargers' compliance with grid operator (TenneT) requirements regarding response time, stability, and accuracy of power regulation. The results underline the potential of EVs in providing grid balancing services, while also identifying areas for improvement, such as increased data frequency and more accurate baseline monitoring, necessary to fully meet technical requirements.




- **EV Chargers (EVSE)**: Physical infrastructure that charges the electric vehicles and can adjust charging rates based on received signals.
- **Charging Station Management System (CSMS)**: Collects and manages data from chargers and communicates with other system components.
- **Enervalis (Smart Charging Provider)**: Processes data from CSMS, generates mock aFRR activation signals, and refines data to ensure accurate and rapid response from chargers.
- **Equigy Platform**: Receives refined data from Enervalis, enabling real-time grid balancing by aggregating EV charging responses.
- **Transmission System Operator (TSO - TenneT)**: Uses the aggregated data and responses for effective and precise management of the electricity grid's balance.

More detailed information can be found in D2.4 and the test report of the aFRR tests.

### 11.4.2 AFRR tests and results

Within the project Enervalis, Equigy, and We Drive Solar successfully executed interoperability tests concerning automatic Frequency Restoration Reserve (aFRR) activation using EV chargers in the Utrecht pilot-site. These tests aimed to validate EV chargers as viable flexibility assets contributing to grid balancing markets.

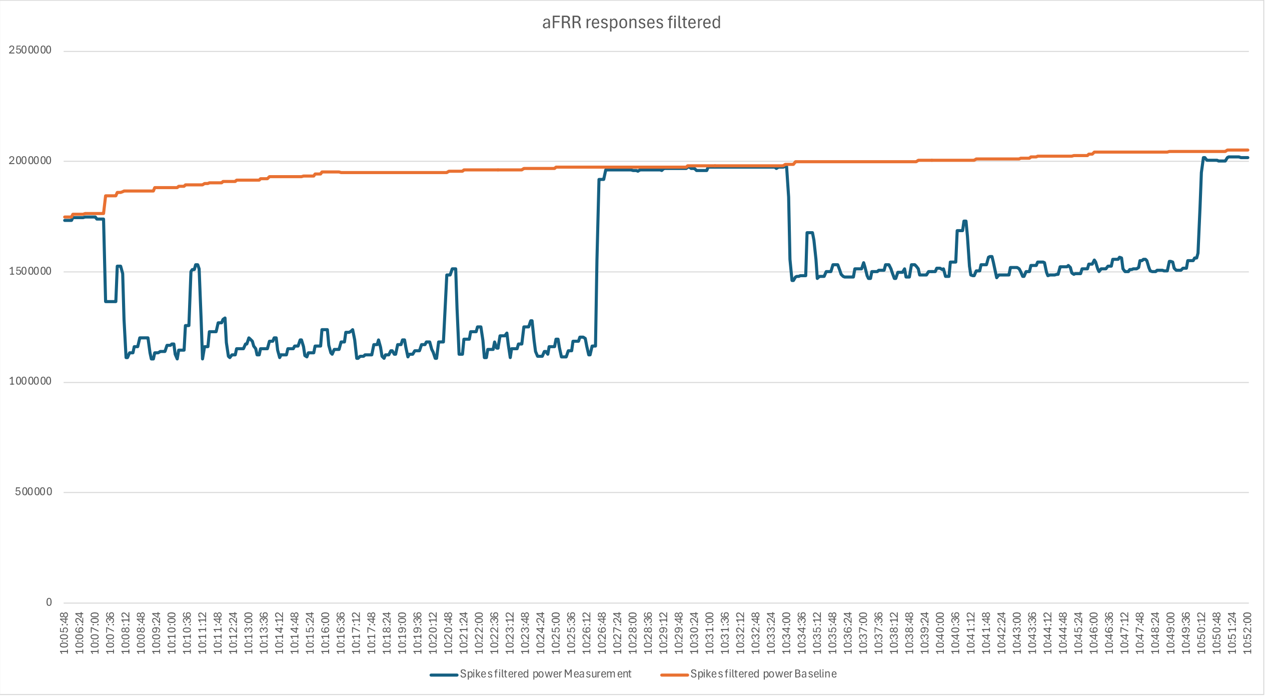
Two structured test sessions were conducted, assessing the response of a managed pool of EV chargers to simulated aFRR activation signals:

- **First Test Session (13.02.2025)**: Two mock activations of -200 kW were executed. Despite initial challenges related to data granularity and baseline calculation accuracy, the test demonstrated rapid charger response with the fleet reaching the target activation within two minutes, well within TenneT's required maximum ramp-up of five minutes. Issues identified, such as the baseline calculation errors and insufficiently frequent charger control commands, were corrected in subsequent tests.
- **Second Test Session (19.02.2025)**: Two additional mock activations of -1 MW and -500 kW were performed. The tests exhibited significant improvements, notably the resolution of setpoint communication issues. Although the 1 MW activation could not be fully reached due to charger limitation of not completely reduce to 0A for safety reasons (individual charger limited to 6 Amps for safety reasons and keep all EV charging sessions active). It could be achieved if a detection algorithm is built in to see what the minimum is charging current for each EV. The subsequent 500 kW test was notably successful, with the setpoint achieved within 12 seconds, significantly outperforming the TSO's required reaction speed.

The figure below illustrates a representative activation scenario from the second test session (19.02.2025), depicting the rapid and effective response of the EV charger fleet managed by We Drive Solar to a -500 kW aFRR activation setpoint.

The activation was successfully executed, significantly faster than the required TSO ramp-up time of five minutes. The graph highlights both the baseline (projected consumption without activation) and actual power consumption measurements, clearly showing the fleet's quick reduction in charging power upon activation.

Although minor deviations from the setpoint were observed briefly during activation periods, the overall fleet response met TenneT’s primary requirements, demonstrating the potential of aggregated EV chargers as reliable grid balancing resources.



Throughout both testing sessions, Enervalis processed high-resolution data at 4-second intervals, ensuring real-time responsiveness essential for aFRR markets. The data were reliably communicated to Equigy, visualized using Grafana, demonstrating stable interoperability between the EV charging infrastructure, Enervalis' algorithms, and Equigy's crowd balancing platform (CBP).

### 11.4.3 Key Findings and Proof of Concept Outcome:

- EV chargers proved capable of meeting rapid ramp-down rates required for aFRR markets.
- Data communication and control frequency emerged as critical factors for compliance with TenneT requirements, with improved performance achieved via more frequent ('on-change push') data exchanges.
- The occurrence of a "mirroring" baseline response, due to sudden increase in data granularity upon activation, was noted and addressed. Subsequent improvements in data communication protocols resolved this issue in follow-up tests.
- Some minor deviations from setpoint tolerances occurred; these were identified as artefacts related to limited data communication frequency and are expected to be resolved through future refinements in data frequency.

### 11.4.4 Recommendations for Further Development:

To achieve full compliance and operational readiness, the following recommendations derived from the tests should be addressed:

- Enhance charger data granularity and frequency to ensure consistent and accurate baseline calculations. This can be achieved by implementing a threshold-based ('delta-monitoring' as defined in the OCPP2 protocol) approach, whereby chargers only transmit measurement updates when predefined deviation thresholds are exceeded. This approach significantly reduces the data stream and minimizes associated data transfer costs. Reconstruction and extrapolation of the full high-resolution data stream can effectively be managed in the backend system.
- Refine algorithms for baseline predictions and data extrapolation methods to eliminate setpoint deviation risks.
- Consider scaling the fleet size or charger capabilities to reliably meet higher activation demands.

By adopting these recommendations, the performance and cost-efficiency of EV charger integrations into aFRR services can be further optimized, enabling broader scalability and market adoption.

Overall, the interoperability tests conclusively demonstrated the technical viability of using aggregated EV chargers to effectively respond to grid frequency regulation signals in near-real time. The SCALE project's proof of concept provides strong evidence to support further development and scaling of EV-based aFRR services across Europe, in alignment with the objectives outlined in the Horizon Europe Grant Agreement.

# 12 Conclusions

Overall seen a lot of progression has been made into deploying V2G functionalities for mass market, but there are still improvements to make. V2G functionalities (discharging an EV both on AC and DC) on itself are working, especially in a controlled lab environment, but for the deployment of V2G to mass market more is needed than only V2G functionalities. For example, when feeding energy back to the grid certain grid codes need to be applied in certain grid situations. Since standards to fully support this are still under development, this means there is still work to do for mass deployment. Nevertheless, the development of V2G is on the right track and the Testlabs will closely monitor and support manufacturers.

# 13 Recommendation

## 13.1 Policy Recommendations to Support EV Charging Test Laboratories and Accelerate V2G Deployment

To ensure a successful and scalable rollout of Vehicle-to-Grid (V2G) technologies in Europe, it is essential to prioritize interoperability, regulatory clarity, and the strategic support of test laboratories. These labs play a critical role in validating compliance with evolving standards, ensuring grid stability, and preventing vendor lock-in. The following recommendations are aimed at European policymakers, national governments, and regulatory bodies to facilitate the transition to a mass-market e-mobility ecosystem.

## 13.2 Regulatory Recommendations

To achieve high levels of interoperability and safety in V2G applications, the deployment of systems must be grounded in finalized international standards. It is strongly recommended that manufacturers implement only published versions of protocols—such as ISO 15118-20 and OCPP 2.1—rather than relying on committee drafts. Within the SCALE project, all EVSEs were tested against OCPP 2.0.1, but full operational capability, particularly for safe discharging sessions under grid codes, requires adoption of OCPP 2.1.

Furthermore, regulations must be aligned with grid code developments—including those led by ACER—to ensure that V2G implementations meet technical requirements such as voltage control, frequency response, and grid-forming capabilities. A clear and harmonized regulatory roadmap is needed to clarify responsibilities during AC discharging sessions—for instance, whether compliance lies with the EV, the EVSE, or both.

In addition, cybersecurity regulation must be strengthened. Test labs should be mandated to evaluate compliance with the NIS2 Directive, including secure handling of TLS certificates, implementation of secure boot, and PKI infrastructure for Plug & Charge. Participation of test labs in cybersecurity stress tests for EV infrastructure should be formalized.

## 13.3 Funding and Investment

While the number of test labs is growing, merely increasing their quantity does not guarantee better interoperability. What is essential is sustained operational support to enable labs—both commercial and not-for-profit—to maintain state-of-the-art testing infrastructure, train technical staff, and keep protocols up to date.

Public investment programs such as Horizon Europe, national innovation funds, or even global initiatives like the U.S. Inflation Reduction Act, should include funding mechanisms for test lab operations. This will support reliable conformance testing, ultimately enabling a smoother and safer V2G rollout.

### 13.4 Public Procurement and Certification

Government-funded EV charging infrastructure—whether through AFIR, regional schemes, or other initiatives—should require products to be tested and validated by accredited test laboratories. This not only ensures interoperability and quality, but also creates a level playing field across suppliers.

Additionally, test labs should be empowered to carry out pre-certification evaluations of grid-compliant V2G systems. This will help streamline market access and support smoother alignment with evolving regulatory requirements.

### 13.5 European and International Coordination Framework

The establishment of a European Interoperability Framework is critical. Such a platform would enable coordination of test procedures, maintenance of a shared certification database, and harmonization of testing methodologies across Member States. This framework should also serve as a mechanism to align with ACER's work on Network Codes, particularly regarding distributed energy resources and grid-forming technologies relevant to V2G.

In parallel, test laboratories should be given a formal consultative role in the development of future grid codes and market designs. The framework should also collaborate with national accreditation bodies, leveraging the European co-operation for Accreditation (EA), to ensure mutual recognition of test results across the EU.

### 13.6 International Collaboration and Knowledge Exchange

Finally, Europe should actively engage in global collaboration through platforms like IEA Task 53, which focuses on harmonizing testing and validation procedures for EV infrastructure. Participation in such initiatives enables benchmarking against global standards, sharing best practices, and aligning interpretations of protocols such as ISO 15118 and OCPP.

### 13.7 Conclusion

To prepare for a mass-market V2G ecosystem, Europe must treat test laboratories as essential digital infrastructure. By aligning regulation, funding, certification, and international collaboration, policymakers can ensure that EVs, chargers, and grid systems interoperate seamlessly—supporting energy resilience, consumer trust, and climate goals. Coordinated support for these labs will be foundational to the success of AFIR, EPBD, and the broader energy transition.

# 14 Future plans

While work package 2.5 has come to an end, interoperability testing regarding V2G will be continued in the future. New models will come to the market and have to be tested. Alignment with other testlabs is both increasing professionalism of the labs, as well as providing valuable input for policy adjustments.

ElaadNL is also looking into purchasing another DC V2G EVSE emulator. This system could be added to the laboratory equipment and act as another verification system for testing the (V2G) interoperability of EVs. Such a system could also help for the development of future testcases and to analyze challenges reported from the field. ElaadNL will also actively keep inviting both EV and EVSE manufacturers to come testing their products at the Elaad Testlab.

One of the DC V2G charging stations is still on route to the JRC lab therefore it could not be delivered on time to be included in this report. JRC will test this charging station on its EMC performance while it is being exposed to different climate scenarios.

Enedis is currently analysing the impact on its activities of EU regulation updates, such as: market design revision, AFIR Member State implementations, EPBD (Energy Performance of Buildings Directive) and data act has been released, there are different topics for which Enedis Labs will be used to measure and estimate robustness of chargers, EVs, but also sub metering devices, looking at their cohabitation with other usages and smart metering infrastructure. Therefore, the topics below are undertaken for testing and simulation strategies:

- Smart metering connection to chargers for Tariffs signals (LINKY Ready concept and function).
- Dedicated metering device for flexibility
- Data exchange and analysis
- Charging infrastructure in multi-Unit dwelling with pre cabling (EPBD)
- Charging and discharging efficiency (losses estimation and measurements)
- Smart charging and bidirectional discharging impact assessment: grid codes implementation & feedback.