Flexible energy systems Leveraging the Optimal integration of EVs deployment Wave

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Deliverable 4.4

Assessment of the potential for edge computing to support e-mobility

Author(s): Roger Valdés, Josh Eichman [IREC], Sergio Orlando [EATON]

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Table 1. Acronyms.

Acronym	Meaning
EV	Electric Vehicle
DC	Direct Current
AC	Alternate Current
M	Month
WP	Work Package
EVSE	Electrical Vehicle Supply Equipment

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CSMS	Charging Station Management System
CSO	Charging Station Operator
EMSP	E-Mobility Service Provider
CS	Charging Station
OCPP	Open Charge Point Protocol
OCPI	Open Charge Point Interface
DSO	Distribution System Operator
V2G	Vehicle – To – Grid
V2H	Vehicle – To – Home

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Executive Summary

Charging point operators, mobility service providers, electric grid operators, energy market participants, and other key stakeholders must establish seamless communication channels to enable the smooth operation of the EV mobility ecosystem. However, as the number of EVs continues to grow in the near future, concerns arise regarding communication delays, data processing, security, and privacy due to the growing traffic on wireless mediums, especially when conducting operations in the cloud.

One option to mitigate these challenges is to offload some of the processing and communication tasks to edge devices which not only enhances user experiences but also ensures the fulfillment of their specific requirements.

The electric vehicle market has been experiencing rapid growth worldwide, leading to an increased demand for robust and intelligent charging solutions. Traditional cloud-based approaches for managing EV charging networks face challenges such as latency, network congestion, and dependence on stable internet connectivity. Edge computing offers a promising alternative by bringing computation and data storage closer to the charging stations, reducing reliance on centralized cloud infrastructure.

This deliverable presents a feasibility study conducted to assess the viability and potential benefits of implementing edge-based solutions in the electric mobility sector. This work aims to explore how edge-computing technologies affect the speed, reliability, security, privacy, economic and environmental impact and scalability of electric vehicle (EV) charging infrastructure.

This study describes all the actions taken by the stakeholders involved in the process of charging an EV. Then, based on the current solutions, the actions that can be shifted from the cloud to the edge are identified and assessed. Three main candidate areas have been identified for opportunities to shift cloud activities to the edge. These include local smart charging, user authorization and adverse event handling. **Local smart charging** considers the impacts of moving the smart charging algorithms from the cloud to the charging station or a location in close proximity to the charging station. This could result in an improvement for security, privacy, latency and reliability, but must be balanced with challenges for environmental impact, economic impact and scalability. **User authorization** through a local authorization list refers to the concept of enabling authorization of charging at the station itself as opposed to having to request authorization on the cloud. This solution could potentially improve the security, latency reliability and environmental impact of the station, but will experience challenges mainly with scalability across the network. **Adverse event handling** refers to the implications for adverse events as they relate to the role of the cloud in supporting charging (e.g., reporting, billing). Several adverse events are explored and the potential to increase the role of edge solutions to support these events.

Current charging systems strike a balance between actions handled at the edge and those handled in the cloud. This hybrid approach allows systems to achieve the best possible performance. This report identifies several areas to shift actions to the edge or to leverage hybrid approaches to further improve the results.

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1. Introduction to Cloud and Edge computing

The objective of this deliverable is to assess the possibilities of edge-computing solution in the EV charging schema. For this, an understanding of the needs and requirements for cloud computing and edge computing solutions is required.

The term "cloud computing" began to take shape during the 1990s, as the internet and network technologies advanced. Companies started offering web-based applications and services that users could access remotely, regardless of their physical location. Salesforce, founded in 1999, was one of the pioneers in providing software-as-a-service (SaaS) through the internet, but it wasn't until the early 2000s that term "cloud computing" was given a formal definition and popularized through [1], a paper from the Berkeley University. It was around the same time that Amazon Web Services (AWS) was launched (2006), playing a significant role in popularizing the concept by providing cloud-based infrastructure services. This marked a major milestone in the commercialization and widespread adoption of cloud computing.

Since then, cloud computing has evolved rapidly, and today it provides a vast array of digital services and applications used by individuals, businesses, and organizations worldwide. Through the utilization of remote servers hosted on the internet such as Amazon Web Service, Google Cloud, or Microsoft Azure, cloud computing offers unprecedented scalability and flexibility, allowing organizations to expand or shrink their resources based on fluctuating demands. The services and solutions they offer include developer tools, database management, machine learning and AI, IoT, robotics, security, etc.

Cloud computing eliminates the need for substantial upfront investments in physical infrastructure, making it cost-efficient for businesses of all sizes. The cloud also enables effective collaboration and access to data and applications from any location with an internet connection, enhancing productivity. However, like any transformative technology, cloud computing is not without its downsides. **Concerns over data security**, **potential downtime**, and **data compliance** have raised questions about entrusting critical information to third-party providers. Additionally, **dependence on internet connectivity** can pose challenges for users in remote or unstable network environments.

In response to some of these limitations, edge computing has emerged as a complementary solution, offering localized data processing capabilities to address specific use cases. While the foundational ideas and technologies that form the basis of edge computing have earlier origins, the term "edge computing" gained prominence around the mid-2010s [2], where it was defined as "any computing and network resources along the path between data sources and cloud data centers". The rise of edge computing can be attributed to factors such as the surge in data from Internet of Things (IoT) devices [3], the necessity for swift decision-making in time-critical scenarios, and the realization that certain computational tasks are more efficiently executed in proximity to the data's source, rather than in a distant cloud data center. During the mid-2010s, discussions surrounding edge computing gathered momentum, spurring various industries to explore its potential applications. [4] presents a detailed survey of the different edge computing models: Cloudlets, Fog computing and Mobile Edge computing; each of them having their own characteristics.

Edge computing strategically complements cloud computing by bringing data processing closer to the point of data generation. This strategic shift translates to reduced latency, augmented real-time data processing capabilities, and a more efficient overall computing architecture. Diverging from the centralized model of cloud data centers, edge computing evenly disperses computational resources

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across diverse edge locations, including IoT devices, gateways, and compact data centers situated in proximity to users and data sources. This decentralized approach translates to faster data analysis and response times, a critical advantage in applications such as autonomous vehicles, industrial automation, and remote monitoring. Furthermore, the localized nature of edge computing addresses concerns associated with data privacy and security by maintaining sensitive data in closer proximity to its source, thereby minimizing exposure to external threats. Edge computing assets are also considered for detection and localization of load attacks against the grid by compromised EV charging stations [5]. Smart V2G frameworks combining edge and IoT technologies present promising results when it comes to grid decongestion [6]. On the other hand, while edge computing excels in contexts requiring minimal latency and heightened data privacy, it may prove unsuitable for endeavors requiring extensive computational resources and large-scale data processing.

In the context of EV charging and V2G systems, both edge and cloud computing play crucial roles in managing various tasks and actions to ensure the efficient operations and to guarantee interoperability between different systems and entities, while regarding security, solutions implementing blockchain to secure vehicular interactions EVCE frameworks have been proposed [7,8].

In general, Edge computing involves processing data closer to the source of data generation, which is more important for real-time low latency tasks such as:

- **real time control and monitoring of processes**: ensuring that the vehicle's status, grid conditions and safety requirement are met in real time,
- **local decision-making**: edge devices can immediate act on data inputs, for optimized energy flow without relying on the cloud communication,
- **emergency events**: if an adverse event is detected the edge device can filter the amount of data that would be required by the Cloud, helping to manage the congestion of the network and to more quickly report the problem,
- **user authentication and authorization**: if edge devices handled this activity, there is a potential to reduce the need for continuous communication to the cloud

Cloud computing involves central processing, storage, and analytics capabilities that are usually defined in tasks that require high computational resources, historical data and larger scale communication/interaction:

- **data analytics**: long term analysis performed for optimization and future planning,
- **billing and payment**: these processes are usually managed by cloud systems, calculating (or receiving) the amount of energy consumed, the price rate, etc.,
- **scalability**: management of a large number of charging stations,
- **user data and profiles**: cloud platform can store user profiles, preferences and history.

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2. Methodology

Deliverable 4.4. develops an understanding for the functionalities, actions and responsibilities of the different stakeholders. The final goal is to understand what actions that are currently being performed on the cloud can be potentially shifted to an edge solution and the qualitative implications of doing so. To do it, an extended review of the state of the art and the main communication protocols between the different stakeholders has been performed, together with the help of the project partners who have been able to provide insights, and information regarding the specifications of the architectures they are currently using.

In section 3 "Introduction to current architecture", the different stakeholders involved in EV charging are described and presented, along with a presentation of the main communication protocols that regulate their interaction.

Section 4 "Actions" describes the actions for which each stakeholder is responsible . These actions comprise data transfers, messaging, metering, power supply, and others. They are presented in a chronological order. An analysis to determine which of these actions could be shifted to edge computing is performed.

Next, section 5 "Assessment of cloud-to-edge transition impact" qualitatively evaluates different indicators such as ecological impact, security, privacy, scalability for the actions that are relevant for a transition from cloud to edge.

Finally, section 6 "Conclusions" summarizes the previous sections and presents the final conclusions and recommendations reached after the assessment of the edge possibilities in the EV charging environment.

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3. Introduction to current architecture

Electric Vehicle (EV) charging has become a vital component of the rapidly expanding electric mobility ecosystem. As the number of EVs on the road continues to grow, it is crucial to understand the key concepts and stakeholders involved in the EV charging process. Studies have been done in order to analyse the present and future trends that EV charging environment is presenting, focusing on architecture concerns such as security against malicious attacks [10].

An EV refers to an automobile powered by one or more electric motors, drawing energy from a rechargeable battery pack. EV users are individuals or entities that own or operate EVs and require access to reliable and convenient charging infrastructure. In order to understand how EV charging is structured right now, some concepts need to be introduced.

In [11], a survey of the charging station infrastructure used for EV charging in the UK is presented. The Charging Station (CS) itself consists of various components. The main components are Electric Vehicle Supply Equipment (EVSE). An EVSE encompasses the physical charging station and associated hardware required to connect the EV to the power grid. It provides the means to deliver electrical power to the vehicle's battery for charging. An EVSE can have one or more connectors, which can allow different types of charging (different vehicle connections, different power provisioning, etc.). The sizing and configuration of the assets in the charging stations are also important facts that are being currently studied. The optimal sizing solution may depend on the challenge of the project, which could range from supporting the increasing number of electric vehicles, to other requirements such as support long-distance trips, to name a few [12].

Figure 1. Eaton Charging Station with different EVSE. It can be noted how the EVSE also have many connectors as presented in the 1-3 tier model from the OCPP [9]. Extracted from https://www.eaton.com/us/en-us/company/news-insights/energy-transition/electric-charging/on-the-go-ev-charging.html

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Figure 2. Example of V2G ready DC EVSE, supporting EV charging via CHAdeMo and CCS standard connectors. The Eaton xChargeIn DC 44/66 (on the left) is designed for public charging or big private parking facilities while the Eaton xChargeIn DC 22 (on the right) is designed for semi-private and private charging facilities and garages and it can be also wall-mounted. Source: Eaton.

In section 2.3. of deliverable D.1.2, Table 2 details the different standards and regulations that EVSEs must satisfy. Amongst them:

(a) IEC 61851, for "On and off-board equipment for charging EVs with supply up to 1 kV AC and 1.5 kV DC",

(b) IEC 61980, for "Wireless power transfer for supplying voltage up to 1 kV AC and 1.5 kV DC",

(c) IEC 62196, for "Plugs, sockets outlets, EV connector and inlets for conductive charging",

(d) IEC 62840, for "Electric vehicle battery swap systems requirements",

(e) IEC 62893, for "Charging cables for electric vehicles for rated voltages up to 0.6/1 kV",

(f) ISO 15118, for "Vehicle to grid communication interface".

As described in the Open Charge Point Protocol (OCPP), the management system that has the role to operate the Charging Stations is called the **Charging Station Management System** (CSMS). The CSMS provides functionalities such as Charging Station Monitoring, Remote Management, Payment and Billing, User Authentication, Data Collecting and Reporting, and Integration with Network Operators. Depending on the architecture requirements, different mid points between the CS and the CSMS can appear, such as **Local Controllers**, which allow a local control of one or various charging stations, which can accelerate the management of the charging stations for operations or communications with low computational power requirement, and also manage the station in case of connectivity issues. Another asset that can appear is a **Local Proxy**, which can allow different charging stations, connected via internet connection, to communicate with the CSMS.

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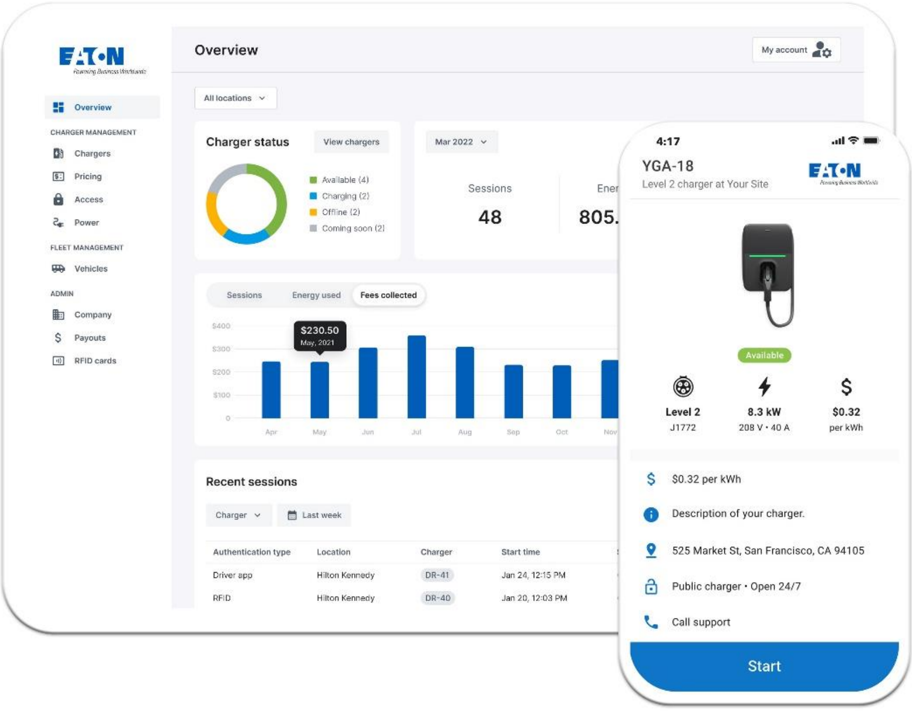

Figure 3. User interface to the Charging Network Manager (CNM) with its features and information. The CNM is a web-based platform for management of operators, EV charging and users. It provides with functionalities of EV charging station configuration, creation of user profiles, manage access rights and billing policies, reporting the transactions and charging statistics. Source: Eaton Charging Network Manager.

Two key stakeholders in the EV **charging sector are** Charging Station Operators **(CSOs) and** Electric Mobility Service Providers **(EMSPs).** CSOs are responsible for managing and operating the charging stations, and are the ones who control the CSMS. They deploy and maintain charging stations, handle maintenance and repairs, and ensure the availability of charging services. CSOs play a critical role in establishing charging networks and providing a seamless charging experience for EV users while at a given charging station. On the other hand, EMSPs offer a range of services to EV users, such as access to a network of charging stations, payment processing, and additional value-added services. EMSPs often collaborate with CSOs to provide a unified charging experience across multiple charging networks, allowing EV users to access charging stations, regardless of their operator. EMSPs may also provide subscription plans, loyalty programs, and other incentives to promote EV adoption and customer retention. Often, the same entity can have the roles of CSO and EMSP at the same time, and in other cases some of their tasks might be interchanged. Finally, to facilitate standardized transactions within the EV charging network, the concept of **tokens** comes into play. The EMSP provide tokens to the EV Users, typically in the form of digital certificates or smartcards, and they serve as credentials that allow the users to access charging services conveniently. By presenting a token at a charging station, EV users can initiate the charging process.

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In addition to CSOs and EMSPs, different entities may appear in this schema. The role of the **Smart Charging Service Provider** (SCSP) may be external contracted parties, which may tell the CSOs or the EMSPs how to optimize the charging session according to different metrics. This SCSP may also have the role of an **Energy Management System** (EMS). This terminology is typically used when different energy assets appear in the charging infrastructure (PV panels, electrical storage, and others). Moreover, if different EMSPs have relationship with different CSOs, a mid-point entity called **Hub** (OCPI documentation) can exist in order to have a central point for communications, and avoid many-to-many communications.

The **Distribution System Operator** (DSO) plays a vital role in the electric vehicle (EV) charging infrastructure by managing the integration of EV charging with the existing electrical distribution grid. Their responsibilities include grid planning and capacity management, coordinating charging infrastructure deployment, integrating smart charging technologies, managing demand response, ensuring grid balancing and stability, data management and monitoring, and compliance with regulations. Through these efforts, the DSO facilitates the integration of EVs into the grid, ensuring reliability, efficiency, and sustainability in the EV charging infrastructure.

Finally, the **Energy Retailers**, which are entities authorized by the market regulator to buy and sell electricity on the market, and represent a contact point between production and consumption. As stated in FLOW D1.1, "they are particularly interested in participating in the V2G market since their involvement will eventually lead to an increase in the amount of energy sold. The introduction of retailers into the market of electric mobility has enabled them to extend the sale of electricity, not only to the end user but also to the EMSP". However, the actions taken by the DSO and the Energy Retailers since they are entities whose actions do not communicate with the CSMS or the CS directly, their actions cannot be shifted to edge computing.

In the following diagram, these stakeholders are shown, together with the relations that they hold. These relations, as it is shown in the next section, are regularized and standardized by the aforementioned communication protocols, which ensure the right functioning and data management between them, and also a basic structure for the solution that different CSOs and EMSPs may reach for their EV charging solution.

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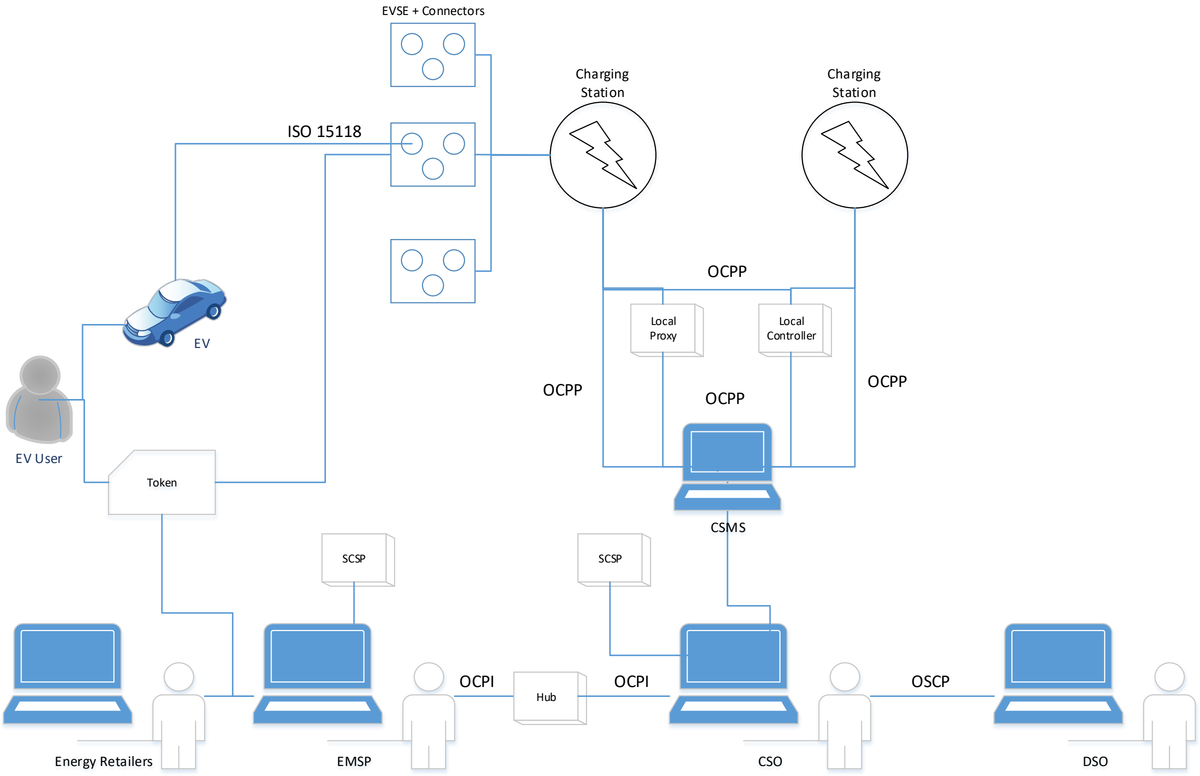

Figure 4. Diagram of stakeholders and their relationships.

Table 2. Stakeholders and entities involved in EV charging.

Entity	Description	Examples
CSO	Charging Station Operator. Responsible for managing the charging station, fixing the power limits of the chargers, enabling the charge for the users, etc. In some cases, CSOs may operate a single charging station, such as in a residential or commercial setting. In other cases, CSOs may operate multiple charging stations, such as in a public charging network. Public charging networks typically consist of multiple charging stations located in different geographic locations, such as along highways, in urban areas, or in public parking lots. In these cases, the CSO is responsible for the management and operation of the entire network of charging stations, including installation, maintenance, operation and billing.	Enel X Way is a global provider of energy solutions, including electric vehicle recharging infrastructure for public or private use. ChargePoint Inc. – ChargePoint is an EV charging network that provides charging stations for businesses, commercial buildings, and public locations.
EMSP	E-Mobility Service Provider. EMSPs offer a range of services to EV users, such as access to a network of charging stations, payment processing, and additional value-added services. EMSPs often collaborate with CSOs	Hubject: Hubject simplifies charging for electric vehicle owners by providing key functions and services including cross-network roaming for

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	to provide a unified charging experience across multiple charging networks, allowing EV users to access charging stations seamlessly, regardless of the operator.	EV charging eliminating the need fo multiple accounts. Last Mile Solutions: Amongst other services, Last Mile Solutions provides a turn-key solution to enable connection of multiple charging networks, manage cards and drivers, create custom pricing and offer services to end-users.
Hub	In the OCPI documentation, the Hub behaves like a connection point between platforms. Platforms are groups of EMSPs, and/or groups of CSOs. These two platforms are allowed to communicate through the Hub.	
EVSE	Electric Vehicle Supply Equipment. The EVSE encompasses the infrastructure and equipment at a site necessary to enable electric vehicle charging. EVSE can have one r more connectors, compatible with different type of EVs. In the OCPP documentation, the 1-3 tier model is defined, where a Charging Station can have different EVSE, which at the same time can have different connectors. The Combined Charging System (CSS) and ISO 15118 protocols describe the communication regulations between the EVSE and the EV.	AC charging: Eaton Green Motion Home/Building AC charger is and EVSE for residential, light commercial and industrial application that provides a type 2 connector and rated power output up to 22kW. DC charging: Eaton Green Motion DC22/44/66 are DC chargers for off-board charging of electric vehicles. The DC 22 is a compact wall-mountable (available also on pedestal) DC charger that provides up to 22kW via both CCS2 and CHAdeMO plugs, V2G ready with ISO 15118 protocol compatibility. The DC 44/66 DC chargers are floor-mounted and designed for public and private parking facilities with rated output power up to 44kW or 66kW DC. They are compatible with V2G and ISO 15118 and they offer CCS2 and CHAdeMO output cable with output voltage up to 500V.
CSMS	Charging Station Management System. In the OCPP documentation, the CSMS is the logical entity that controls the Charging Station. The CSO controls the CSMS to give orders to the CS.	The Eaton Charging Network Manager (CNM) enables the connection and management of virtually any charging station whose communication conforms to the OCPP v1.6J standard allowing EV users to mix and match hardware and network options freely. The CNM also offers features for easy station management, driver access, pricing policies and payment processing – providing load management and support for demand

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		response (e.g., using Open ADR 2.0 open-source standard).
Local Controller	In the OCPP documentation, different Charging Stations can be locally managed by a single Local Controller, which communicates with the CSMS. Typically, the controller is embedded within one charger, and it provides charging control for multiple outlets (different connector standard as well as AC or DC charging). multiple solutions exist as well where the charging station controller can be modular to have extendable modules that accommodate the charging management of more chargers (charging unit).	Pheonix Contact makes a range of AC and DC charge controllers in their CHARX product line.
Local Proxy	In the OCPP documentation, the Local Proxy delivers messages between Charging Stations and the CSMS, through an internet connection.	
EV	The electrical vehicle.	
EV User	User of the electrical vehicle. Needs to interface and share data with the CSO or EMSP to receive charging services (EV related data, billing data, location data if a navigation service is contracted, etc.).	
Token	Access given by the EMSP to EV users, to enable the use of Charging Stations.	
SCSP	Smart Charging System Provider. In the OCPI documentation, the SCSP can provide limits to the power distributed in the Charging Station. The SCSP can appear in different topologies. For example, it can communicate to an EMSP, or to the CSO.	
EMS	Energy Management System. In the OCPP documentation, the EMS is in contact with third parties (CSOs, EMSPs, etc.), and it can also have direct contact with the CSMS. It can set charging limits to the chargers. The EMS can be responsible for the management of a smart circuit, including the Charging Stations, the grid demand, and different energy generators (e.g., PV Panels, on-site storage).	There are many companies that offer energy management systems including: Siemens, Schneider Electric, Bamboo Energy.

3.1. Communication protocols

Efficient communication and interoperability are fundamental to the success of electric vehicle (EV) charging networks. In order to achieve this, standardized protocols have been developed to govern the exchange of data and commands between the different stakeholders involved in the charging

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process. These protocols play a crucial role in facilitating smooth interactions within the EV charging ecosystem. Below is a summary of some of the key protocols that regulate communication among EVs, charging stations, central management systems, and grid operators.

ISO 15118 serves as a common language for communication between EVs and charging stations. Developed by the International Organization for Standardization (ISO), ISO 15118 enables advanced functionalities like plug-and-charge. This means that when an EV is plugged into a compatible charging station, they can securely and autonomously establish communication without requiring additional authentication or user intervention. The last update of ISO 15118 also facilitates bi-directional power flow and Vehicle-to-Grid (V2G) capabilities, allowing EVs to not only draw energy from the grid but also supply energy back.

The Open Charge Point Protocol (OCPP) ensures efficient management and control of charging stations. OCPP is an open standard protocol that defines a common set of commands and messages for communication between charging stations and central management systems. It allows Charging Station Operators (CSOs) and other stakeholders to remotely monitor, control, and manage charging stations. With OCPP, CSOs can initiate and stop charging sessions, monitor energy consumption, retrieve charging station status, and collect metering data. The widespread adoption of OCPP has fostered interoperability, enabling charging stations from different manufacturers to integrate into a unified network.

Another important protocol is the Open Charge Point Interface (OCPI), which focuses on enabling communication between different charging networks and service providers such as CSOs, Electric Mobility Service Providers (EMSPs), Navigation Service Providers (NSPs), and others. OCPI standardizes the exchange of information related to charging station locations, availability, pricing, and other relevant data. By adhering to OCPI, EMSPs can access and provide services across various charging networks. OCPI simplifies the process of locating and accessing charging stations, making it easier for EV users to navigate and utilize the charging infrastructure, regardless of the specific network operator.

In the context of demand response capabilities in EV charging, the Open Automated Demand Response (Open ADR) protocol plays a crucial role. Open ADR facilitates communication between grid operators and charging infrastructure, enabling adjustments to charging power and patterns based on grid conditions and electricity demand. By coordinating charging activities, Open ADR allows the grid to manage and optimize the charging load, alleviating strain during peak periods or dynamically responding to fluctuations in renewable energy generation. The protocol promotes grid stability, load balancing, and the integration of renewable energy sources into the EV charging ecosystem.

By adhering to these protocols, stakeholders ensure interoperability, standardization, and secure communication among EVs, charging stations, CSOs, EMSPs, and grid operators.

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4. Actions

4.1. List of actions

In this section, a detailed description of the actions performed by each stakeholder during the charging process are presented. This work builds on the findings in FLOW D3.1 "Requirements and Specifications for the Development of Interoperable Software". Focusing on charging events, the actions shown are considered required in the charging session procedure. The end-goal of this section is to be able to identify processes are occurring in the cloud and could be shifted to the edge. Each one of these actions will be presented in the following functional blocks:

- Data Transfer,
- Authorization,
- Availability,
- Transactions,
- Smart Charging,

and each have different characteristics:

- ID: identification number to cite the action in this document.
- Protocol: if applies, in which protocol/s this action is considered.
- Description: description of the action.
- Executed by: who executes the action.
- Received by: if applies, who receives the action.

The functional blocks and their actions have been extracted following the OCPP v2.0.1 documentation, along with the description of some of the actions. The actions that have been included in this document are the ones that are most important to the study. Some of the actions that were not considered in this protocol have been added, given that the OCPP documentation focuses on the CS - CSMS communication.

Data Transfer

This functional block includes any type of message transmission between actors.

Table 3. Data transfer actions description.

Data Transfer Actions					
ID	**Protocol**	**Action**	**Description**	**Executed by**	**Received by**
DT1	OCPP	Data Transfer from CSMS to the Charging Station.		CSMS (Cloud)	CS (Edge)
DT2	OCPP	Data Transfer from CS to the CSMS.		CS (Edge)	CSMS (Cloud)
DT3	OCPP	Data Transfer from EV to CS.		EV (Edge)	CS (Edge)
DT4	OCPI	Data Transfer from EMSP to the CSO		EMSP (Cloud)	CSO (Cloud)

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DT5	OCPI	Data Transfer from CSO to the EMSP		CSO (Cloud)	EMSP (Cloud)
DT6	OCPI	Data Transfer from EMSP to the SCSP		EMSP (Cloud)	SCSP (Cloud)
DT7	OCPI	Data Transfer from SCSP to EMSP		SCSP (Cloud)	EMSP (Cloud)
DT8	ISO 15118	Data Transfer from EV to EVSE		EV (Edge)	EVSE (Edge)

The Data Transfer actions cannot be shifted to edge or cloud, as they simply state that the overall solution needs to support this type of communication between parties.

Authorization

This group describes all the authorization related functionalities, giving different option of authorizing and authenticating users. Some comments:

- The **Authorization Cache** can be used to speed up the authorization process at the Charging Station, since using a locally stored cache means that the user does not have to wait for the Charging Station to check the authorization with the CSMS.
- The **Local Authorization List** is a list of identifiers that can be synchronized with the CSMS. It allows authorization of a user when offline and faster (apparent) authorization response time when communication between Charging Station and CSMS is slow. The CSMS can synchronize the list by either sending a complete list of identifiers to replace the Local Authorization List or by sending a list of changes (add, update, delete) to apply to the Local Authorization List.

Both the Authorization Cache and the Local Authorization List need to be considered as **Edge solutions** for charging stations that are still keeping all their authorization responsibilities in cloud databases. As it is explained in D.1.1,

Table 4. Authorization actions description.

Authorization Actions					
ID	**Protocol**	**Action**	**Description**	**Executed by**	**Received by**
A1	OCPP	EV Driver Authorization	When a Charging Station needs to charge an EV, it needs to authorize the EV Driver first before the charging can be started or stopped. Make it possible to start a transaction using a RFID (C01), start button (C02), credit card (C03), pin-code (C04).*(C01,..., C04 is the terminology used in OCPP for this use cases).	CSMS (Cloud)	EV driver (Edge)

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A2	OCPP	Offline Authorization of unknown Id	To allow or deny automatic authorization of any "unknown" identifiers that cannot be explicitly authorized by Authorization Cache entries. The solution implemented needs to determine what to do in this case.	CS (Edge)	EV driver (Edge)

Availability

This functional block specifies how the Charging Station can inform the CSMS of its current availability for starting new transactions. For the CSO it is important to know if a Charging Station is available for new EVs to be charged. The CSO wants to know this information so they can tell EV Drivers whether the Charging Station is available. To know this, the Charging Station should send any status changes of itself or one of its EVSEs to the CSMS. For the CSO it is very helpful to know the status of the transaction, therefore the Charging Station can send detailed status updates to the CSMS. This can be very useful when helping an EV Driver if they experience problems during charging.

When a fault is detected by the Charging Station it can send a message notifying the CSMS about the fault. When the CSO wants the Charging Station to no longer start new transactions, it can change the availability. For example: they need to do maintenance on the Charging Station, and for this reason they do not want the Charging Station to be in use. The CSO can also change the availability for one or more EVSEs. For example: A customer calls, complaining about a broken EVSE on the Charging Station. The CSO can then set the Connector to unavailable, making it impossible for an EV Driver to use that Connector. It is also possible to make the Charging Station or a Connector available again with a command from the CSMS.

These actions cannot be provided as an edge solution, given that the communication with the CSO, via the CSMS (cloud) is of vital importance for this functionality.

Table 5. Availability actions description.

Availability Actions					
ID	**Protocol**	**Action**	**Description**	**Executed by**	**Received by**
AV1	OCPP	Status Notification	CS sends a notification to the CSMS to inform the CSMS about a Connector status change.	CS (Edge)	CSMS (Cloud)
AV2	OCPP	Change Availability EVSE/Connector	To enable the CSMS to change the availability of an EVSE or Connector to Operative or Inoperative. The CSMS requests the Charging Station to change the availability of	CSMS (Cloud)	EVSE (Edge)

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			one of the EVSEs or Connectors to Operative or Inoperative.		
AV3	OCPP	Change Availability Charging Station	To enable the CSMS to change the availability of a Charging Station. The CSMS requests the Charging Station to change the availability. A Charging Station is considered Operative when it is charging or ready for charging. A Charging Station is considered Inoperative when it does not allow any charging.	CSMS (Cloud)	CS (Edge)
AV4	OCPP	Lock Failure	To prevent the EV Driver from charging while the Connector is not properly locked. This use case describes how the EV Driver is prevented from starting a charge session at the Charging Station while the Connector is not locked properly.	CS (Edge)	

Metering

This functional block describes the functionality that enables a Charging Station to send periodic and possibly clock-aligned meter values.

Table 6. Metering actions description.

Metering Actions					
ID	**Protocol**	**Action**	**Description**	**Executed by**	**Received by**
M1	OCPP	Sending transaction related Meter Values	To sample the energy meter or other sensor/transducer hardware to provide information about the Charging Stations' transaction related Meter Values. The Charging Station samples the energy meter or other sensor/transducer	Charging Station (Edge)	CSMS (Cloud)

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			hardware to provide information about its transaction related Meter Values. Depending on configuration settings, the Charging Station can send Meter Values during a transaction.		

Smart Charging

This functional block describes all the functionalities that enable the CSO (or a third party) to generate a smart charging profile for the charging of the vehicles in a CS:

· **Internal Load Balancing**: This concerns internal load balancing within the CS, where the CS controls current/power per EVSE. The Charging Station is configured with a fixed limit, e.g. the maximum current of the connection to the grid.

· **Central Smart Charging**: The typical Cloud solution where the CSMS can optimize with a general view of more than one asset: in this case, the CSMS may optimize a group of CSs at the same time and consider other assets such as PV generation forecasts, electrical storage, etc.

· **Local Smart Charging**: Local Smart Charging describes a use case in which smart charging enabled Charging Stations have charging limits controlled locally by a Local Controller, not the CSMS. This type of smart charging assumes the existence of a Local Controller, which is a logical component that controls a group of Charging Stations. A typical use would be a number of Charging Stations in a parking garage where the rating of the connection to the grid is less than the sum the ratings of the Charging Stations. Another application might be that the Local Controller receives information about the availability of power from a DSO or a local smart grid node.

· **External Smart Charging Control Signals:** Cloud solution where a third party (such an EMS/SCSP) computes the charging profile for the station. This profile can be computed by considering DSO signals, energy assets, and others. The optimal profiles can be communicated directly to: (1) the CSMS, (2) a Local Controller, (3) a specific CS.

The CS is blind to who is doing the optimization, but it is important in this analysis to assess the difference between cloud and edge solutions in this specific step of the charging process.

Table 7. Smart Charging actions description.

Smart Charging Actions					
ID	**Protocol**	**Action**	**Description**	**Executed by**	**Received by**
SC1	OCPP	Third party Optimization	A third party performs an optimization considering DSO signals, electricity tariffs, energy generation forecasts, etc.	SCSP, EMS (Cloud)	
SC2	OCPP	Central Smart Charging	The CSMS computes the optimal profile.	CSMS (Cloud)	
SC3	OCPP	Local Smart Charging	Alternative scenario to SC2. To enable charging limits to be set at the	Local Controller (Edge)	EVSE (Edge)

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			Charging Station by a Local Controller.		
SC4	OCPP	Internal Load Balancing	Alternative scenario to SC2. To enable internal load balancing within the Charging Station and between EVSEs.	CS (Edge)	EVSE (Edge)
SC5	OCPP	Set Charging Profile	To enable the **CSMS** to influence the charging power or current drawn from a specific EVSE or the entire Charging Station over a period of time.	CSMS (Cloud)	CS (Edge)
SC6		Central Optimization (connection failure)	The CS has to be able to generate a charging profile in case of a connection failure.	CS (Edge)	

Transactions

A transaction is a record of the interaction between the EV and the CS service. It tracks the start/end of the session, the energy exchange, etc. This functional block covers how to start, manage and stop a transaction.

Table 8. Transaction actions description.

Transaction Actions					
ID	**Protocol**	**Action**	**Description**	**Executed by**	**Received by**
T1	OCPP	Start Transaction Options	To inform the CSMS that a transaction at the Charging Station has started (**using P02**). There are a lot scenarios to consider: (1) start when a connection between EV and EVSE is confirmed, (2) when a parking bay occupancy detector detects an EV, (3) when the EV driver is authorised to charge, (4) when the energy flow starts.	CS (Edge)	CSMS (Cloud)
T2	OCPP	Stop Transaction options	**At least one of the following 6 scenarios:** S1: Stop a transaction when a parking bay	CS (edge)	CSMS (Edge)

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			occupancy detector no longer detects the EV. S2: Stop a transaction when communication between the Charging Station and the EV is lost. (for example: cable unplugged) S3: Stop a transaction when the driver is no longer authorized. S4: Stop a transaction when energy transfer stops. This will also mean the transaction stops when the EV stops taking energy, for example when the battery is too hot. S5: Stop a transaction when EV driver ends authorization		
T3	OCPP	When cable disconnected on EV-side: Stop Transaction	This use case covers how a transaction is stopped when the EV Driver unplugs the cable at the EV side.	EV driver (Edge)	
T4	OCPP	Transaction locally stopped by IdToken	This use case covers how the EV Driver can stop a transaction when he wants to leave the charging station.	EV driver (Edge)	
T5	OCPP	Transaction stopped while Charging Station is offline	This use case covers how the Charging Station starts and stops a transaction while operating offline.	CS (Edge)	

4.2. General operation of a charging session

Next, the procedures involving a charging session are chronologically described. In the various steps, the use case terminology presented in Tables 3 – 8 is used.

A charging session develops as follows:

1. **Connection.** The EV Driver begins the interaction with the Charging Station by plugging in the charging cable first. The CSMS is notified (T1).

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2. **Status change communication.** The CS sends a notification to the CSMS about a status change using AV1.
3. **Authorization request**. The EV Driver needs authorization (A1).
4. **Charging request.** The EVSE/CS sends a charging request to the Local Controller or the CSMS. This charging request could include a variety of data including initial SOC, departure time/energy required, battery capacity, etc.
5. **Charging profile calculation/Optimization**. The charging profile can be calculated at different sites (*Local Controller,* CSO (CSMS), or a third party SCSP).
    a. **Charging Station.** The Charging Station may apply a simple optimization such as Internal load Balancing between EVSEs simultaneously charging (SC4).
    b. **Local Controller.** An option considered in the OCPP documentation, the Local Controller can set the charging limits at the Charging Stations (SC3). It is worth noting that if a charging profile is computed at the Local Controller level, then:
        i. **Computational power will be lower,** which implies simpler optimization.
        ii. **In order for the local controller to be aware of the needs of third parties,** some communication with these external (cloud-based) parties needs to occur: DSO needs, CSO/EMSP aggregation needs, Electrical Storage-PV panel management (self-consumption), etc.
    c. **SCSP/EMS**. If it is computed by an external control system (SC1), it can:
        i. **Send the charging limits to the CSMS.** To inform the CSMS of a charging schedule or charging limit imposed by an External Control System on the Charging Station with ongoing transaction(s). An External Control System sends a charging limit/schedule to a Charging Station. This limit is sent to the CSMS, who sets a charging profile.
        ii. **Send the charging limits to the Local Controller**. To adjust the charging limits according to the External Control System requirements, an external control system sends a charging limit to the Local Controller. The Local Controller notifies the CSMS, calculates the new charging schedules and sends the profiles to all Charging Stations for which the charging profile has changed.
6. **Charging request response.** The CSMS or Local Controller communicates the charging profile to the CS.
7. **During Charging Session: Energy metering and updated charge.**
    a. The EVSE meters energy values related to the transaction (e.g., SoC, total energy transmitted).
    b. The Charging Station sends a transaction request message, for offloading Meter Values to the CSMS (MV1).
    c. Periodically, a new charging profile is computed and sent to the Charging Station as described in step 5.
8. **Charging session Termination.** Consider the different scenarios presented in T2 Description (see Table 8**Error! Reference source not found.**).
9. **Billing information exchange**. The CS or EVSE provides necessary billing information to the CSMS (CSO), including session start and end times, energy consumed, and any additional fees or discounts.
10. **Billing and payment processing**. The CSO or EMSP calculates the total cost of the charging session based on the billing information received from the EVSE. The user's payment method is charged accordingly, and a transaction record is created.

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4.3. Real life use case

4.3.1. Background

V2X (Vehicle to Everything) refers to the technologies (HW, SW and communication network) that enable the electric vehicle (EV) acting as mobile energy storage (Li-Ion battery) and providing services to the electric grid and/or connected loads. The motivations and the application of this technology are standard energy storage of electricity for opportunity usage; emergency back-up power to the grid (or a sub-grid) as well as grid services such as peak-shaving and load shifting. With reference to the use-cases above mentioned V2X is usually referred to as V2H (Vehicle to Home), V2B (Vehicle to Building) or V2L (Vehicle to load) if the services are mostly focused on the local grid; and as V2G (Vehicle to grid) if grid services are provided.

Many use-cases and projects have been carried out on the V2X technology, focusing both on the technological development of HW and SW and the control and communication challenges behind the V2X. A use-case for V2X that embrace both V2G and V2H features was identified and investigated by EATON in the past few years, and it is presented and summarized in the following paragraphs.

4.3.2. AC V2G/V2H Project overview

The project aimed at developing and assessing the value proposition of AC V2G and V2H use-cases with a focus on the HW design implementation, the communication networks and the computational capabilities while enabling smart bidirectional charging functions.

The AC V2X use-case developed by EATON focuses on developing and demonstrating AC V2G/V2H for residential applications, which includes:

- Develop and identify system architecture that enables V2H/V2G scenarios including hardware, communications, controls, and protections.
- Develop bidirectional Level 2 AC charger using EATON'S smart energy management circuit breaker (EMCB).
- Develop smart load center with islanding and reconnect capability to enable transitions between V2H and V2G.
- Working with vehicle OEM and utility partners to demonstrate the system using real EV and utility server.

4.3.3. Main components of the demonstrator

To describe the use-case and therefore the overall project a list of components forming the demonstrator (as shown in fig.5) is provided as follows:

- Electrical grid (utilizing IEEE 2030.5 as a communication network protocol and to enable the bidirectional V2G).
- Electric vehicle with onboard bidirectional charger (smart inverter)

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- Smart distribution panel that features an islanding switch device, simulated home loads powered through EMCBs, UPS for control circuitry and smart circuit breakers power supply during transitions.
- Power control system (PCS) includes control, communications, and operation logic that enables the transition between V2G and V2H and vehicle and provides energy management during islanded operation.
- User interface for monitoring, configuration, and user input.
- The bidirectional level 2 EVSE with integrated EATON's Energy Management Circuit breaker (EMCB).
- SECC enables communication with EV and backend including aggregator and power control system (PCS) and runs on edge devices.
- Service platform aggregator for EV charging and discharging that runs on cloud and managed by grid operator.

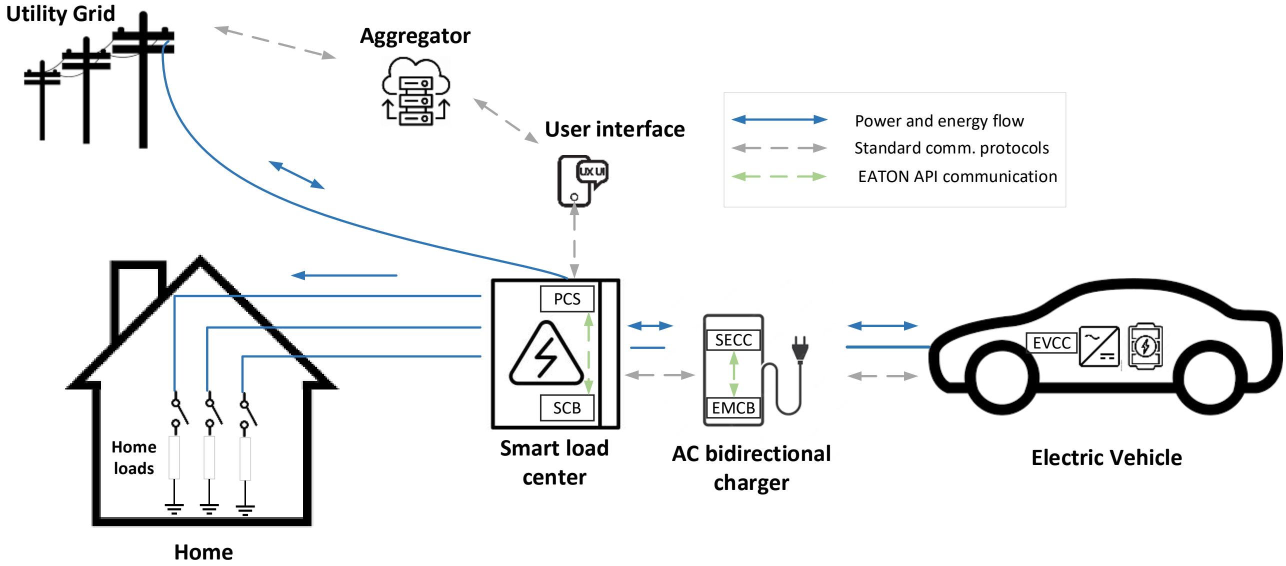

Figure 5. AC V2G/V2H use-case: reference diagram.

4.3.4. Project demo focus

For the AC bidirectional V2X demonstrator use-case the following scenarios were developed and demonstrated:

- V1G with managed charging.
- V2G with grid support functions.
- V2H for home emergency backup power with energy management (240 Vac).

The project centers on the assessment and exploration of V2X technology with a specific emphasis on the V2H and V2G. Notably the application analyzed are the AC V2H/V2G charging, with respect to the standardized protocols IEEE 2030.5 and SAE J3027, in particular:

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- Communication with EV is performed via standard SAE J3027 and IEEE 2030.5.
- Communication with back-end, aggregator is ensured by protocol IEEE 2030.5.
- Communication with EV EMCB and smart load center control is via Eaton API.

4.3.5. Conclusion

The primary goal of project was to demonstrate the AC level 2 V2G/V2H capabilities, showcasing the hardware and software solutions adopted as well as proposing a communication architecture. However, it could be noticed that this use-case leverages the edge computing since most of the critical components including the power system control, SECC and HEMS are located at the edge devices, while the cloud computing was considered for aggregator functions. In general, the computing at the Edge enhances responsiveness and ensures that vital functions are not reliant on cloud connectivity. On the other hand, the cloud primarily handles other functions that can be retained in the cloud due to their less time-sensitive nature for centralized control.

The authors of this deliverable report observe that, in such use-case:

- Edge computing can be beneficial to reduce the latency by improving real time-operation like V2H and V2G.
- The system becomes more robust, capable of maintaining essential functions even during outages (cloud outages and electrical outages thanks to the back-up power for this use case).
- Costs are optimized as edge devices can be efficiently scaled.
- Visibility of the Edge devices is provided to the grid operator.
- It was possible to enable the integration of DER connected to the edge.

Therefore, this project showcases the potential of edge computing to enable V2X technology offering a strategy for smart charging, grid support and home energy management that is flexible, secure, and sustainable. The future of V2H/V2G technology lies in the synergy of edge and cloud computing and the project sets a promising precedent for its implementation.

4.4. Opportunities for shift

With knowledge of the general processes for engaging in electric vehicle charging and their interrelations, this section explores potential for implementing these processes in the cloud or edge. The location of the components of a charging station are depicted in Figure 6, recognizing that some are located on-site and others are off-site (OCPP documentation [4]). OCPP is focused on the communication between the Charging Station and the CSMS, where the CSMS is the cloud-based central management system. The possibility of working with local controllers that have local storage and computational capacities can help to expand the possibilities of moving components from the cloud to the edge:

a) **Authorization.** Due to the need of contacting the CSMS. A local authorization list in the local controller could accelerate the authorization process and enhance user experience.
b) **Smart charging**. Typically, the **optimization** is a complex computation that requires high computational power in order to reach the optimal solution. However, depending on the needs of the solution, the EMS can be a local EMS only concerned about the station

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management, blind to third parties needs such as DSOs, CSOs and EMSPs. This possibility provides the potential to shift much of the computational power used in the cloud, to the edge.

c) **Adverse events handling.** When a malfunctioning happens, many of the decisions that are made to ensure effective operation of the station are decisions taken with low computational power required (e.g., following logic trees: if this, that; else,...).

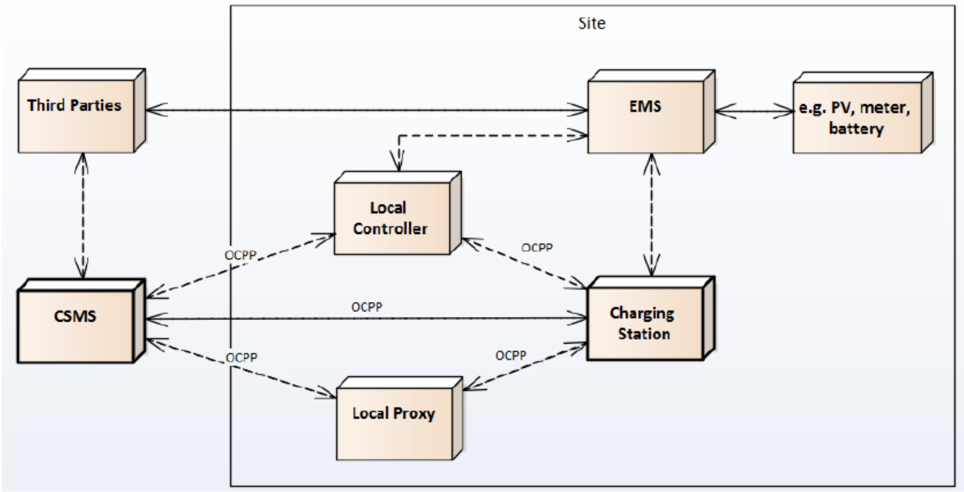

Figure 6. Components in a setup using OCPP. Extracted from OCPP documentation [4].

The objective is to identify which of these actions related to user authentication/cache storage, optimization and adverse events management can be executed by Local Controllers and the trade-offs occurring from moving from cloud to the edge.

Building on the actions described in **Table 3. Data transfer actions description.Table 3** to **Table 8**, the actions considered the most likely candidates for shifting from cloud to edge are described in **Table 9**.

Table 9. Candidate actions to be shifted to edge solutions.

ID	Action	Original Cloud Solution	Edge Solution
A1	EV Driver Authorization	When a Charging Station needs to charge an EV, it needs to authorize the EV Driver first before the charging can be started or stopped. Make it possible to start a transaction using a RFID (C01), start button (C02), credit card (C03), pin-code (C04).*(C01,..., C04 is the terminology used in OCPP for this use cases).	Perform all authorization actions through local authorization lists, storage in local edge devices.
SC1	Third party optimization	A third party such as an EMS/SCSP, performs an optimization considering DSO signals, electricity tariffs, energy generation forecasts, etc.	(1) **SC3. Local Smart Charging**. To enable charging limits to be set at the Charging Station by a Local Controller. (2) **SC4. Internal Load Balancing**. To enable internal load balancing within the Charging

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			Station and between EVSEs.
SC2	Central Smart Charging	The CSMS computes the optimal profile.	(1) **SC3. Local Smart Charging**. To enable charging limits to be set at the Charging Station by a Local Controller. (2) **SC4. Internal Load Balancing**. To enable internal load balancing within the Charging Station and between EVSEs.

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5. Assesment of Cloud-to-Edge transition impact

In this section, a qualitative impact analysis is performed for the actions that can be shifted to the edge described in section 4.4. Figure 7 summarizes the actions taken by different stakeholders and highlights four specific actions (in blue text) that have potential to be shifted from the cloud to the edge.

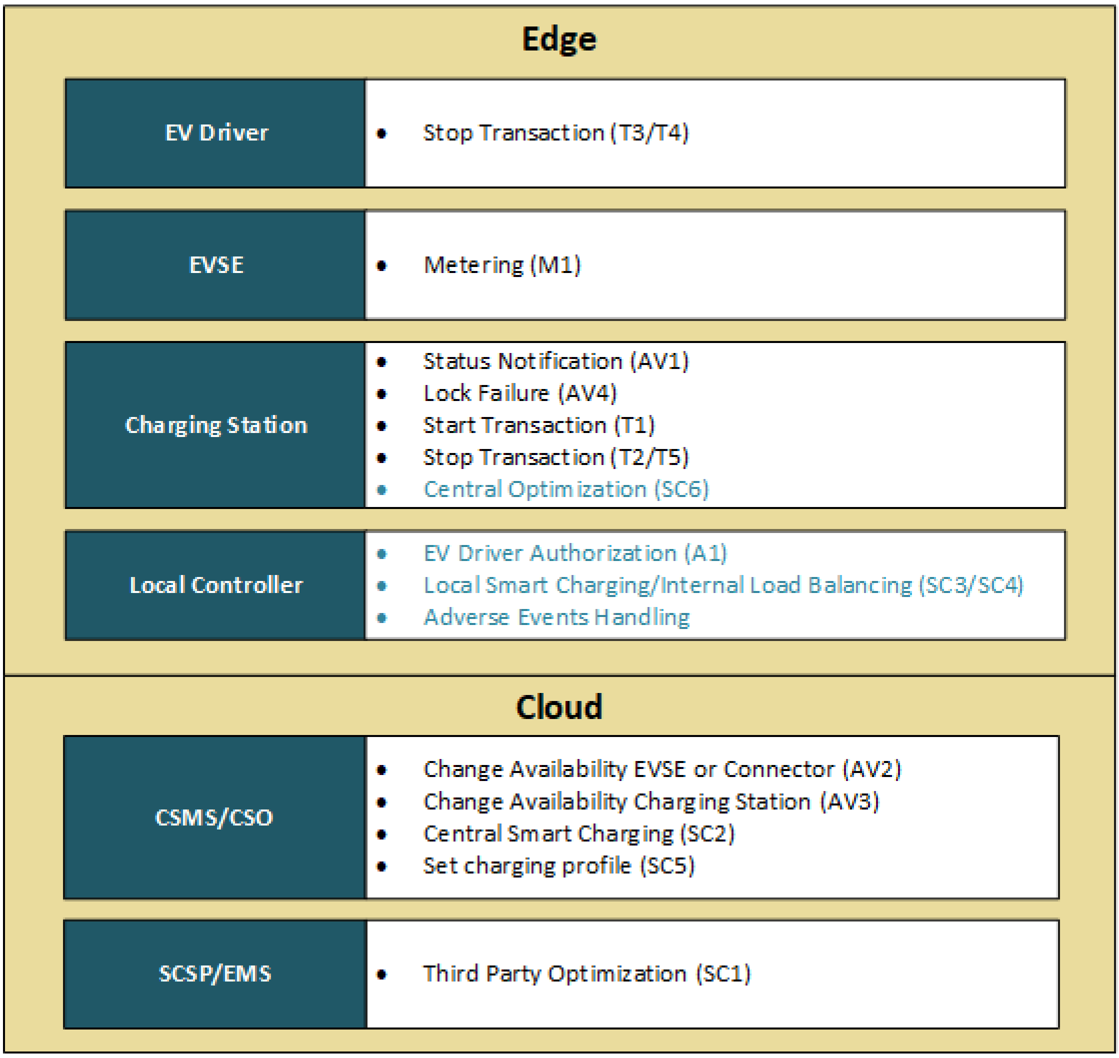

Figure 7. Actions taken by stakeholder. In blue, actions that can be shifted from cloud to edge.

The adoption of Edge computing could be beneficial to many different aspects:

- **Sustainability and environmental impact**: the transition to the Edge have several competing factors that should be considered with respect to environmental impact. Reducing the need to transmit large amounts of data over long distances and store that data in data centres can improve the energy efficiency of electric vehicle charging process. This is particularly true as the number of chargers, sensors and other support devices increase. On the contrary, distributing the computation and storage at the edge will require additional hardware at the edge, which will require energy and materials to produce, install and maintain. Whereas cloud

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systems can reallocate their resources dynamically, underutilized processing and storage capacity at charging stations represents an inefficiency of this architecture.

- On the **economic level**, the implementation of Edge devices requires investment in local infrastructures and following the utilization discussion above, represents an inefficiency from a capital investment point of view. However, there is a potential reduction in operational costs over the lifetime of the equipment coming from the cost of transmitting data, and depending on the ownership structure of the cloud system, there are also potential cost savings from purchasing processing and storage resources from a third-party.
- The **speed** and **reliability** are improved. Edge computing improves the user experience because the system interactions (such as charging session start, disconnection, etc.) have lower latency and require less extensive use of an internet connection to operate. Furthermore, as the mobility sector continues to expand, improve reliability and offer new services for smart charging, bidirectional charging, support for the grid, integration with renewables and on-site storage, etc., the importance of reliable, low latency real-time decision making is critical to improve customer experience and provide reliability during operation.
- **Security** of the charging network can be improved. In an edge configuration, since sensitive data and decision are largely exchanged locally, cybersecurity can be improved through reducing the size of the attack surface. Also, the edge computing offers real-time protection on account of the faster response times and because the data is locally stored which reduces the risk of unauthorized accesses by external actors.
- Customer **privacy** can be improved. Performing processing locally, in a distributed manner and minimizing the amount of data and personal information that is exchanged reduces the opportunity that this information is compromised.

However, it is important to observe that since Edge involves local devices, best practices in security and data privacy measures should be adopted for each of the devices, connections and communication must be managed. Additionally, it is important that the Edge computing decisions respect the local norms and standards, which is easier to guarantee in a hybrid Cloud-edge architecture. Furthermore, the transition Cloud to Edge must also be accurately assessed depending on the local infrastructure, the local market and the use-case application needs. Because in many cases a combination of Cloud and Edge can still be a better solution by exploiting the strengths of both solutions to improve the user experience, the sustainability, cost, privacy and security and contributing to a more efficient energy transition.

The three areas identified for shifting from cloud to edge described in Section Opportunities for shift4.4 are presented below with a summary of the benefits and challenges that arise during the shifting process.

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Table 10. Summary of the impact of the cloud-to-edge shift for the proposed items. Green (improve), yellow (depends), red (worsen), grey (no impact).

Edge solution	Security	Privacy	Latency	Reliability	Environment Impact	Economic Impact	Scalability
Local Smart Charging	Improve	Improve	Improve	Improve	Depends	Worsen	Worsen
Local Authorization List	Improve	Improve	Improve	Improve	Improve		Worsen
Adverse event handling	Improve		Improve	Improve			

In general, the **environmental impact has to be accurately assessed**, given that edge solutions will decrease the amount of information to be transmitted, but also increase the amount of hardware deployed and energy consumption at each site in the charging stations.

Local smart charging

When it comes to local smart charging, several aspects must be considered. First, by reducing the scope of the smart charging problem to only include on-site chargers or local chargers, the **quality** of the optimal solution will almost surely decrease limiting the opportunity to provide flexibility to the grid and, depending on utility rate structure, this could result in higher operating costs. A local edge server will not have the same computational power as a cloud server. Simple solutions with low computational requirements can be easily deployed in an edge solution, with an increase in speed and responsiveness; however, the value of this shift must be balanced between the security, privacy improvements and any cost reduction from data transmission against the added cost of hardware implementation and maintaining the local solution. The environmental impact is similarly a balance between energy reductions from more limited transmission of data versus the changed in on-site hardware. From a scalability perspective, replication through the cloud has a significant advantage over the edge solution which would require software that would there is development required for both edge management of the site or local area and cloud management of many stations. It is valuable for either cloud or edge smart charging that over-the-wire updates are enabled and secured appropriately.

Local authorization list

Regarding the **local authorization list** for user-authentication, implementing such a list could potentially accelerate the authentication process, enhance user experience, and contribute to the overall efficiency of the charging network. By storing authorized user data locally, at the charging station level, users might experience reduced authentication latency, allowing for quicker and efficient access to the charging infrastructure. This approach could also potentially reduce the load on the CSMS authentication server, improving its responsiveness and scalability during periods of high demand. It would also allow vehicles to charge in the event of loss of connectivity to the CSMS.

The implementation of a local authorization list has potential to improve **security** but it still must be secured appropriately. The system could use similar security measures in the authentication process as in the cloud solution, but benefits from less reliance on internet connection. On the other hand, if a recent change to the authorization list has not be passed to the local system, there is the potential that an authorized user will be denied usage at the site. This would encourage a hybrid approach where

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authorization is handled at the edge unless a user is denied, at which point the request will be sent to the cloud, thereby limiting data transfer without compromising usability.

Considering **privacy**, the main question is whether the authorisation list could inadvertently expose user data or compromise anonymity. Cloud versus edge solutions represent a trade-off between sending more data to each charging site (even if a user will never use that site) versus sending data for each charging event, which will likely increase the volume of communication to the site. The authorization list sent to the sites can be simplified to minimize the amount and usability of the information exposed in the event the database is compromised:

Table 11. Database for local authorization list.

FieldName	Type	Memory
ID_TOKEN	Integer(9)	36 Bytes

Where the cloud version of this database should keep track of more information regarding the user, billing information, etc. This local database would need to be updated by the CSMS every time that there is an update in the cloud database. Including only the ID_TOKEN.

When it comes to **environmental impact**, the amount of storage required for this task can be easily estimated. Looking at Table 10, the memory reserved for the ID_TOKEN field can be used to approximate the total memory of this database. Let N be the number of tokens registered in the service. Then, in total, the storage required is 36·N. For example, in an urban area with 1 million of EV users, the total storage required would be 0.036 GB. The impact of having to include such storage in CSs has to be weighed against the CO_2 footprint of constantly validating users in a cloud server.

In terms of **scalability**, the local authorization list edge solution comes with clear challenges when compared to its associated cloud solution. This is due to the fact that the increase of charging stations will proportionately increase the number of physical storage required for the authorization lists, with repeated information between charging stations. In a cloud solution, the database is stored just once. In order to mitigate the increase of memory required for the local authorization list, a possible solution is to assign to each user a location to where he /she is registered, given that, for example, a Spanish EV user does not need to be registered in local authorization lists in Portugal. Implementing a hybrid approach that first looks for local authentication before relying on the cloud server could reduce communication traffic while also mitigating the locality issues.

Adverse events

To ensure the highest level of safety, safety related issues are generally not handled by a cloud solution and are handled on-site with the charging system. This section focuses on the implications for adverse events as they relate to the role of the cloud in supporting vehicle charging (e.g., reporting, billing).

Generally speaking, the adverse events of electrical faults happening during an EV-EVSE interaction as defined in this deliverable refer to:

- network level faults,
- measurement faults (voltage level, insulation monitoring, current, etc.),
- system level and electrical component level (which can be from power electronic in OBC (off board charger) or DC charger.

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Causes and examples of adverse events during a charging session, which could interrupt the EV charging session and its related services are:

- Faults in the charging equipment/charger: like malfunctioning of electric system, power electronics, measurement unit, insulation, thermal heating, failure in the communication, etc.
- Faults or malfunctioning in the vehicle: communication failure, faults of power electronics in the case of OBC (On board charger), insulation fault and grounding fault.
- Faults on the Electric supply network: interruption on the voltage supply or power quality issues.
- Safety: emergency if risk is detected by the system, like overheating, short circuits, etc., which will immediately interrupt the session. There are various reasons for short circuits and overloading during a charging session, most of the causes include insulation issues, cables interruption, bad wiring or maintenance.
- In such situations, the transaction management would be impacted on both the economic and the service level. For example, generally, if the charge is interrupted before completing the charging session, then the user could be charged only for the energy provided, if appropriately recorded. The Charger or the system could record the energy profile and the adverse event and then issue the bill based on this calculation. The component in the charger that records the information is the local system/controller in the charger that stores information on the energy provided, charging time, type of vehicle and other details.
- The handling of adverse event can involve both components in the edge and cloud platform. Edge computing is ideally the best to deploy to get real-time responses, such as immediate interruption of the charging session, while cloud is more suitable for the data management, the historical data analysis and the optimization of long-term operations as well as planning.

In the event of a sudden charging interruption the computational distribution between Edge and Cloud varies depending on the specific architecture of course and on the system specifications and priorities. As an overview:

1. **Edge computing** is particularly suitable for the **control on real time and quick decision**, therefore in the **event of an adverse situation** the Edge would be a **main element to take immediate control and safety actions** such as interruption of the charge and put in safety the vehicle and the charge equipment. The edge could activate a local emergency system that interrupt the energy flow reducing risks and damages.
2. **Cloud computing** is still the main element **responsible** for **data management and analysis, transaction management** (economic management of the interruption and billing), **optimization, software updates and sending feedback** to **edge devices.**

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6. Conclusions

In this work, a comprehensive examination of cloud and edge technologies within the environment of Electric Vehicle (EV) charging has been performed. This began by describing the multitude of stakeholders involved, alongside the different communication protocols that regulate their interactions. These protocols, central to the functioning of the EV charging environment, define both cloud and edge use case solutions, and so for future work it is imperative to perform a market analysis to assess the path in which companies are developing their solutions.

To our study, one of the most important prospects lies in the potential shift toward edge solutions, primarily for the actions taken by the Charging Station Operators (CSOs). For this task, we identified the essential component actions of a charging session with detail, to discern which could be effectively shifted or conducted at the edge.

From our analysis, different points are concluded. Edge technology plays a pivotal role in the realm of adverse event handling. The ability to efficiently manage charging sessions and the overall charging infrastructure proves indispensable when confronted with the different possible failures, from connectivity issues to battery overheating, short-circuits, equipment malfunctions, etc. A robust edge implementation that prepares charging sessions for all possible eventualities becomes imperative in ensuring the seamless operation of EV charging stations.

Moreover, edge technologies could provide value for user authentication, potentially enhancing the overall user experience, while reducing communication traffic and reducing latency. With the transition from petroleum refuelling to electric recharging comes the need for drivers to adapt to longer charging times, and to different interaction with charging station user interfaces. Swift communication with these interfaces can contribute significantly to the acceptance of this new paradigm in public EV charging. While the edge solution in this context is not without challenges (e.g., recent authorization updates), there is also potential to implement a hybrid cloud-edge solution that can provide the benefits of the edge solution while also allowing mitigating the challenges with support from the cloud. This represents a particularly unique configuration that should be further explored.

While local computations could handle charge optimization, the bulk of this process is likely to remain in the cloud. On the flip side, with regard to adverse event management, charging stations must possess the capability to execute basic protocols and routines for charging session management, in the event of connectivity issues with the Charging Station Management System (CSMS).

Inevitably, the cloud will continue to play a pivotal role, as charging stations require some degree of management by a CSMS. Other stakeholders, such as Electric Mobility Service Providers (EMSPs), Distribution System Operators (DSOs), and Network Service Providers (NSPs), have their own needs and interests in the charging ecosystem. Therefore, the cloud central hub facilitating communication between these entities cannot be avoided.

In light of these multiple considerations, the solutions developed by companies for charging station management are poised to remain hybrid in nature. A real-life use-case example presented in section 4.3 by Eaton partners, shows the integration of edge technologies across various phases of the charging session of their private home charging solution.

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In summary, our study reveals a dynamic landscape where cloud and edge technologies work together to lay the groundwork for the future of EV charging. This synergy between edge and cloud works towards enhanced reliability, privacy, scalability, user experience, and adaptability, ensuring that the solutions provided by the companies in the EV sector can be delivered with the highest degree of safety while also providing a reliable, low cost, user-friendly result.

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