



Review

OCPP Interoperability: A Unified Future of Charging

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Abstract: Electric vehicle (EV) adoption grows steadily on a global scale, yet there is no consistent experience for EV drivers to charge their vehicles, which hinders the important EV mass market adoption. The Open Charge Point Protocol (OCPP) is the solution to this challenge, as it provides standardization and open communication between EV infrastructure components. The interplay of the OCPP with open cross-functional communication standards boosts driver experience on the one hand, while the charging station itself is integrated into a renewable energy ecosystem. This paper presents a deep dive into the combination of the OCPP with the OpenADR protocol, the Open Smart Charging Protocol (OSCP), the ISO 15118, and eRoaming protocols to explore possibilities and limitations. Furthermore, we suggest LoRa communication as an alternative to IP-based communication for deep-in building applications. Hence, this paper reveals the next important steps towards a successful EV mass market transition powered by user-friendliness and green energy.

Keywords: EV infrastructure; standardization; interoperability; communication protocols; NEVI

1. Introduction

User-friendliness and large scale zero-emission vehicle infrastructure deployment is critical to achieving the White House net-zero emissions target by 2050 [1]. However, a recent survey of EV users reported substantial frustration with chargers being too slow, too crowded, or not operable [1,2]. In combination with range anxiety during long distance travel [3], a skeptical attitude toward EVs has evolved, which hinders a commitment to private or commercial EV ownership and prevents a profitable EV mass market adoption.

Interoperability within the EV infrastructure provides the solution to that challenge by nurturing a consistent and familiar EV driver experience powered by a reliable and green ‘distributed energy resources’ (DERs) energy ecosystem [4].

Interoperability in this case is two dimensional:

- (1) Consumer facing;
- (2) Technical or systems facing.

Consumer-facing interoperability includes the physical accessibility of a charger, universal payment methods at every charging station (CS), or ‘one-matches-all’ coupler hardware to be consistent with current re-fueling experiences for internal combustion engine (ICE) vehicles.

Technical interoperability encompasses standardized technical protocols and testing procedures with the aim of achieving consumer-facing interoperability and excellent user experience on a large scale. Standardized and generic data communications between different chargers and their respective central management systems (CMSs), together with a uniform data exchange between CMSs and third-party backends, such as e-mobility service providers (eMSPs) and capacity providers (CP) (counting utilities, distributed systems operators (DSOs), and cloud-based energy management systems (EMSs)), are the heart of interoperability.

It is with this consideration that Ampure (formerly Webasto Charging Systems) chargers strongly support and utilize the major de facto open-charger-to-cloud communication protocol in the US, the Open Charge Point Protocol (OCPP). Ampure chargers provide an



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interoperable, flexible, and expandable infrastructure platform that can integrate with a broad range of eMSPs, charging station operators (CSOs), automakers (OEMs), and CPs, fostering critical consumer interoperability and friendliness (Figure 1).



Figure 1. **Left:** Our charger is connected via OCPP1.6J to a cloud-based EMS, enabling capacity-based smart charging. **Right:** Deep-in building application of our industrial chargers facilitating LoRa. Reprinted from Ref. [5]. Most application protocols for data communication, such as the OCPP, require IP-based communication. For deep-in building charging technologies that demand low bandwidth and long-range (for example the transfer of battery status data in warehouses), a LoRa connectivity shall provide a great alternative to Wi-Fi, BLE, and cellular. LoRa facilitates long-range communication up to 10 miles and consumes ultra-low power. Reprinted from Ref. [6]. Via a LoRa gateway and encryption techniques, battery data can securely be transferred to the backend system.

2. Overview of Today's EVSE Protocol Landscape

This paper provides a unique and important overview of the Open Charge Point Protocol (OCPP) [7] by the Open Charge Alliance (OCA), and the interaction of the OCPP with cross-functional open standards, such as the OpenADR protocol [8], the Open Smart Charging Protocol (OSCP) [9], the ISO 15118 standard series [10], and eRoaming protocols (Figure 2) [11–14].

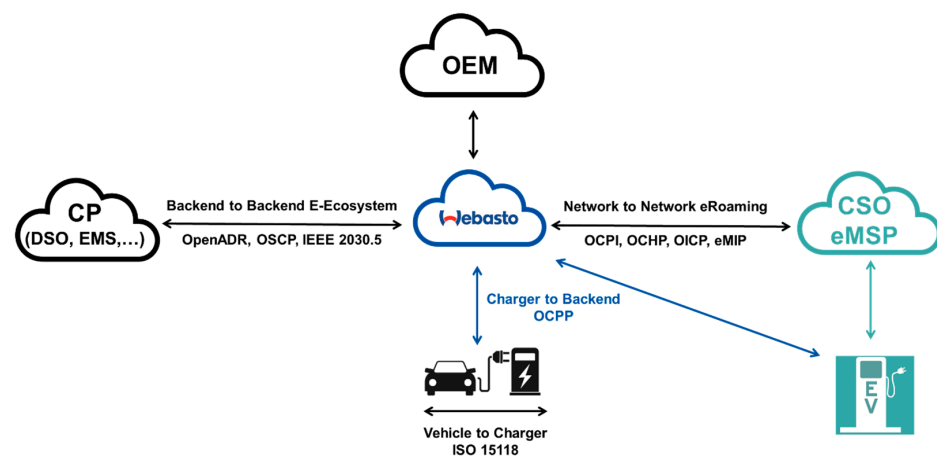


Figure 2. Communication protocols at a glance. The OCPP is the major open de facto communication protocol for charger-to-backend communication. Cross-functional backend communication is multifaceted and facilitates different protocols for different needs. For the communication between capacity providers (CPs) and central management systems (CMSs), protocols such as the OpenADR protocol or the Open Smart Charging Protocol (OSCP) are in place. For eRoaming, which requires CMS to CSO/eMSPs backend communication, the Open Charge Point Interface (OCPI) protocol, the Open Clearing House Protocol (OCHP), the eMobility Interoperation Protocol (eMIP), and the Open InterCharge Protocol (OICP) can be used to serve hub-based or bilateral eRoaming structures. The ISO 15118 is an international standard series that contains specifications for secure, local, and bidirectional communication between EVs and chargers.

The intention is to facilitate an understanding of how the landscape of open and standardized application protocols boosts driver experience, while the growing EV in-

frastructure is integrated into a green and stable energy ecosystem. This review outlines the relevant characteristics of a protocol for its mass adoption success, possibilities, and limitations of open standards.

3. An Excerpt of Today's Leading Communication Protocols in the EV Industry

3.1. The OCPP, the OpenADR Protocol, and the OSCP Are Fundamental Contributors to a Scalable and Clean Electric Transportation Ecosystem

The major de facto and open protocol for charger-to-backend communication in the US (and globally) is the Open Charge Point Protocol (OCPP), which was initiated and has been maintained by the Open Charge Alliance (OCA).

The large-scale electrification of vehicles, fleets, and marine ports presents a threat to the grid, and as such it is crucial to bring chargers into the equation of energy demand and response systems. The combination of the OCPP with the Open Automated Demand Response (OpenADR) protocol or the Open Smart Charging Protocol (OSCP) turns a charger into a flexibility provider that can react to changes in demand response (DR) within a distributed energy resource (DER) energy ecosystem. Accordingly, an uninformed charging process can be converted into a smart technique, which is able to throttle or postpone a charging process based on currently and locally available grid capacity.

3.1.1. The Open Charge Point Protocol (OCPP)

The IP-based Open Charge Point Protocol (OCPP) is the major de facto and open communication protocol between a charging station (CS) and its respective central management system (CMS, Figure 3). The kick-off of a global and open protocol to standardize charger-to-backend communication in the EV industry was initiated by the E-Laad Foundation (now ElaadNL) in the year 2009, and it has been maintained and continuously developed by the members of the Open Charge Alliance. Due to the active support and contribution of major stakeholders and experts in the industry over decades, the open protocol has grown into a globally acknowledged communication protocol.

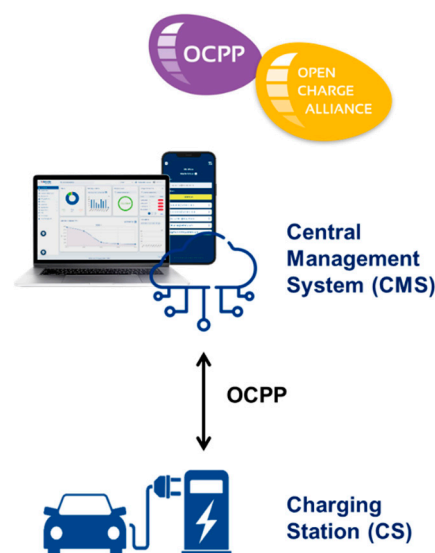


Figure 3. The OCPP is the major de facto open communication protocol between a charger and its CMS in the US and globally. The OCPP enables any CMS to connect with any charger, regardless of the vendor or manufacturer, if the CMS and the charger are compliant with the same OCPP version 1.6J or 2.0.1.

The OCPP enables any central management system to connect with any charger, regardless of the vendor or manufacturer, if both are compliant with the same OCPP version 1.6J or 2.0.1 [7]. This key attribute allows for a “mix and match” of chargers and a vendor agnostic infrastructure deployment, which is required for a rapid and sustainable

growth of the charging industry. In addition, the real-life application of the OCPP with versatile charger networks gives insight into potential interoperability gaps, which can be flushed out and improved by the ongoing development of the protocol. The advantage of the Open Charge Alliance and the OCPP is the constant development and integration of new features and improvements based on real-world desires, needs, and lessons learned within the EV community. At the same time, this advantage also brings challenges and limitations. In comparison with proprietary and closed communication protocols, the OCPP does leave some room for technical interpretation between participants. Test tools, test labs, and global interoperability testing events, such as the “Plugfest” organized by the Open Charge Alliance and CharIn, mitigate the interoperability risk and are on the rise.

The dominant protocol version in the field is 1.6J; however, the industry has moved on to version 2.0.1 to benefit from the extended feature set such as demand response, load balancing, and tariff management, which are crucial functionalities of a modern and stable EV infrastructure. The OCPP 2.0.1 was released in March 2020 and serves Level 2 and DCFC techniques (GB/T, CHAdeMO, and CCS). It enables extended functionalities in the availability of chargers, payment, and reservation methods, smart charging options, and certificate management [7]. In addition, version 2.0.1 is required for a successful connection to the important ISO 15118 standard series [10], which enables Plug and Charge, and vehicle-to-grid applications. While the OCPP 1.6J and 2.0.1 are not backward compatible, all new versions, such as OCPP 2.1, which is in the release pipeline and includes for example generic interfaces for payment terminal integration, will be backward compatible moving forward.

OCPP interoperability unifies the charger network and, as such, substantially enhances the driver experience, with less stranded assets within a charging radius. Any stranded charger can be picked up by any operator using the same OCPP backend configuration.

Furthermore, an operator has the flexibility to purchase equipment from multiple vendors, which allows the operator to be manufacturer agnostic. Such interoperability fuels a fair market competition in the EVSE space, granting access to newcomers and not being solely dominated by a few established majority holders in the market.

3.1.2. Combining the OCPP with the OpenADR Protocol to Convert a Charger into a Smart Load Flexibility Provider

The production of renewable energy has become more and more decentralized, with individual businesses or households contributing to energy production through solar, wind turbines, and electric energy storage (EES) systems. An energy consumer has become an energy “prosumer”, who produces and consumes renewable energy. In general, with so many active and different energy contributors, there is a huge desire for all of them to communicate and work together effectively to ensure grid safety and reliability [8,15].

To that aim, capacity providers—including utilities or distribution systems operators (DSOs)—use the OpenADR standard, which is maintained by the OpenADR Alliance, to enable a bidirectional IP-based communication between their top node(s) and aggregators or end devices.

The OpenADR protocol allows the coordination of end device responses to changes in currently and locally available energy supply/demand [16]. The protocol encompasses event messages, reports, and registration services, as well as availability schedules for dynamic price- and capacity-based programs [17]. The combination of the OCPP and the OpenADR protocol equips EV chargers with the capability to react to locally and currently available DER grid capacity, and makes a charging process flexible and smart (Figure 4).

While the OpenADR protocol standardizes the messaging and DR information exchange between a capacity provider’s backend and the charger’s central management system, the OCPP contains all required action commands to trigger the desired charger reaction. Such a charger reaction can be postponing a charging process, the consideration of priority charging, and the optimization of charging schedules [17].

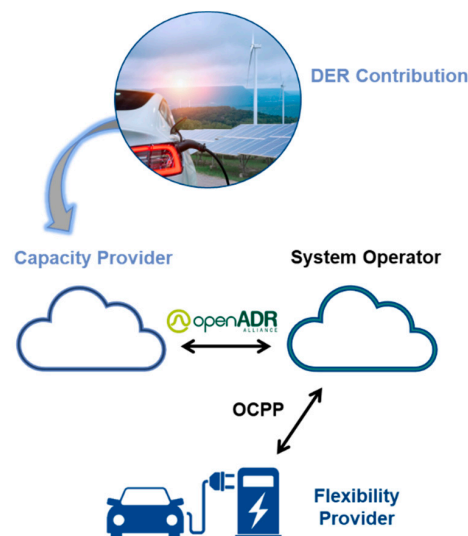


Figure 4. The line-up of the OCPP and the OpenADR standard turns a charger into an efficient load flexibility provider, which is integrated into a green DER energy ecosystem. While the OpenADR protocol standardizes the messaging and DR information exchange between a capacity provider's backend and the charger's central management system, the OCPP action commands initiate the desired reaction of the charger.

On the consumer side, the interaction of the OCPP and the OpenADR protocol saves cost per consumed energy unit (kWh) while maximizing the amount of renewable energy used for EV charging.

3.1.3. Combining the OCPP with the OSCP to Convert a Charger into a Smart Load Flexibility Provider

Similar to the OpenADR protocol, the Open Smart Charging Protocol or OSCP [9] takes the integration of EVs into a larger, dynamic, and flexible energy ecosystem (including photovoltaics, stationary batteries, heat pumps, etc.) into consideration. The OSCP standardizes the communication between the capacity provider, which can be a cloud-based EMS for example, and the charger's central management system, while also taking a 24 h prediction of the local available grid capacity into consideration [9]. Such communication capabilities of a charging station with the grid turns an operator into a flexibility provider, capable of matching charging profiles within local capacity trendlines, e.g., capacity-based smart charging (Figure 5). Additionally, the operator can request the optimal EV charging energy demand, to prevent line or grid overloading.

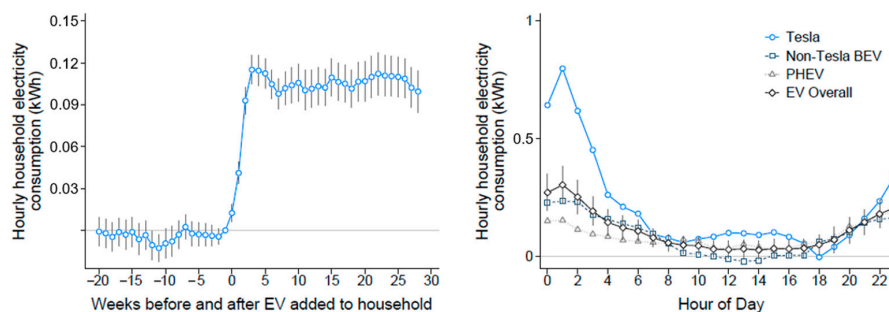


Figure 5. Impact of EV adoption on household electricity. **Left:** EV adoption (week 0) increases household electricity consumption by 0.12 kWh hourly or ca. 3 kWh per day. **Right:** effects are concentrated between 10 p.m. and 6 a.m., when vehicles are plugged in overnight to recharge. Reprinted from Ref. [18]. Services, such as capacity-based smart charging, help optimize energy consumption in the case of multi-dwelling unit applications, where multiple drivers might demand electricity at the same time.

3.2. Combining the OCPP with the ISO 15118 Standard Series for a Safe, Sustainable, and Automated Charging Network

The ISO 15118 “Road vehicles—vehicle to grid communication interface” is an international standard series, which contains specifications for the bidirectional communication between an electric vehicle and a charging station (CS) [10]. The ISO 15118 has been developed by the “International Organization for Standardization” (ISO) and represents a significant milestone in the advancement of electric vehicle technology. The standard addresses and solves the challenges that are associated with the interoperability and communication between EVs and the charging infrastructure, such as cybersecurity, ease of use for the driver, and smart dis-/charging technology. The series provides a comprehensive framework for the communication protocol between electric vehicles and chargers, converging seamless, green, and automated charging processes [10].

The ISO 15118 consists of multiple parts, each focusing on different aspects of the communication interface between electric vehicles and the charging infrastructure. Part 1, for example, serves as an introduction to the series, outlining general principles and defining use cases for vehicle-to-grid communication, such as the Plug and Charge use case. Part 2 of the series delves into the technical specifications of the network and application protocols. This includes the definition of the communication architecture, data formats, and security mechanisms, which are necessary for secure and reliable communication between electric vehicles and the charging infrastructure. The ISO 15118 standard series is designed to be scalable and adaptable to evolving technologies and industry requirements. Its modular structure allows for updates and additions to accommodate emerging features and advancements in electric vehicle technology.

The ISO 15118 addresses the security aspects of communication between electric vehicles and chargers, which is key to data security. It specifically outlines the security measures necessary to protect the communication interface from potential cyber threats. This includes authentication and authorization mechanisms, data integrity protection, and encryption techniques to ensure the confidentiality of the exchanged information. The Transport Layer Security (TLS v1.2) protocol is used to establish the encrypted communication session, while elliptic curve Diffie–Hellman (ECDH) is used to validate the process for one charging session [10]. AES-128-GCM (ISO 15118-20) is utilized to encrypt and decrypt instructions during a charging session using the TLS session key. The elliptic curve digital signature algorithm (ECDSA) will further verify the authenticity of the sender and the integrity of the received message (via SHA-256 as a cryptographic hash). These industry standard protocols ensure the charging process is secured, and minimize the risk of damaging the charger or vehicle from compromised devices [10,19].

Two major use cases of the ISO 15118 are Plug and Charge (PnC), i.e., automatic authorization and payment upon connecting an EVSE with the car, and vehicle-to-grid (V2G), i.e., a vehicle can supply energy back to the grid during down times. The PnC use case catalyzes the user experience, as a driver can simply plug the coupler into the vehicle and the necessary communication and initiation of the charging process occurs automatically, provisioning customer excellence without the necessity to rely on a secondary digital or physical payment option. The V2G functionality allows electric vehicles not only to receive power from the grid but also to feed stored energy back into the grid, contributing to grid stability and potentially creating new revenue streams for EV owners. This application is particularly important for fleet scenarios, which run on predictable schedules and thus can potentially support the demand during peak hours with the V2G technology.

3.2.1. The ISO 15118 Plug and Charge (PnC) Use Case

The ISO 15118 PnC use case provides an automated charging and payment process upon plugging the charger into the EV. The charging authentication and authorization is accomplished using digital certificates that are exchanged between the EV and the charger [10,19] (Table 1). No form of active consumer involvement is required, and the

billing process happens in the back without any actions required by the driver (other than initially adding the payment to their platform).

Table 1. Basic certificate fields for a typical X.509v3 certificate, as used in ISO 15118 [10]. The EV’s certificate is called the identity certificate, and is used to authenticate the EV to the charger. Similarly, the charger’s digital contract certificate is used to authenticate itself to the EV.

Certificate Field	Description
Version	Version of certificate
Serial number	Unique number of certificate
Signature algorithm	Used signature algorithm
Issuer	Entity, who has issued and signed the certificate
Validity period	Time period, in which the certificate is valid
Subject	Entity, to which the certificate is issued
Public key	Public key corresponding to a private key
Issuer UID	Optional issuer unique identifier
Subject UID	Optional subject unique identifier
Extensions	Optional
Signature	Signature of the certificate generated by the issuer

The digital certificates are stored in the onboard system of the EV and then provided to the charger once plugged in. The certificates are signed by a third-party certificate authority (CA), and, in combination with encryption methods, the ISO 15118 ensures secure EV–charger communication and protected user contract data [20].

The vehicle’s certificate is the identity certificate, which is used to authenticate the EV to the charging station. Similarly, the charger’s digital contract certificate is used to authenticate the charger to the EV. By exchanging these two certificates through local charging cable communication, the EV and the charger can negotiate charging parameters, charging rates, and billing details agreed upon by the EV owner and the operator [10].

3.2.2. ISO 15118 Vehicle-to-Grid (V2G) Use Case

Electrical energy storage (EES) is one of the most effective support systems for balancing a green and dynamic DER grid [15]. EV traction batteries can be mobile resources, with typical capacities of 30–100 kWh of electrical energy [21]. For reference, an average household in the US consumes 30 kWh electrical energy per day [22]. Fleet applications, such as school buses, can be a predictable energy prosumer. The vehicles feed energy back to the grid during peak demand time when they are not in use and charge again off peak before they are required to dispatch. This technological milestone shall have a major positive impact on grid stabilization, while offsetting running costs, and help make electrification transformation sustainable and scalable. In a complete green energy cycle, the charger’s central OCPP management system can be connected via OpenADR or OSCP to a capacity provider to receive dynamic updates on DER power availability.

The ISO 15118 provides the communication protocol between vehicle and charger. This communication solution together with further inverter requirements equips a charger with the potential to bring back green electrical energy from the vehicle’s traction battery (originating from photovoltaics or wind power for example) to the grid (Figure 6) [10]. This energy can be used to power homes and businesses during peak demand periods, during emergencies, or when renewable energy sources are not active. In addition, EV owners can potentially generate an additional income stream by providing power to the grid, which reduces the cost of electrification [10].

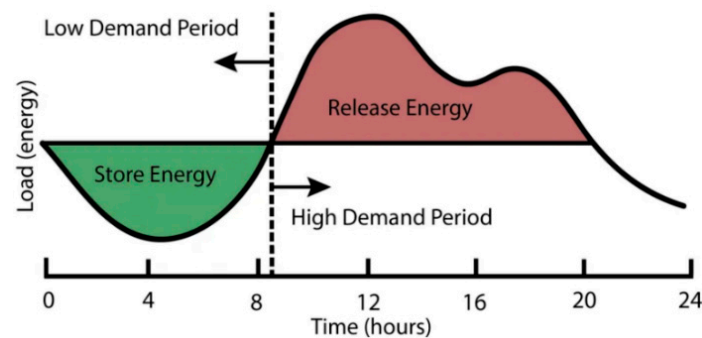


Figure 6. Electrical energy storage (EES) refers to the process of converting electrical energy into a stored form that can later be converted back into power when needed. Reprinted from Ref. [15]. The ISO 15118 V2G provides the communication basis between a vehicle and an EVSE to sell back (green or cheap) electrical energy from the EV's traction battery to the grid when demand is high.

In the ISO15118 V2G application, the EV and the charger authenticate each other by exchanging their identity and contract certificate, respectively. The charger must be able to support the bidirectional V2G data transfer and electricity flow between the EV and the grid. For data communication, the ISO 15118-20 can be implemented, which is currently in the process of being extended to AC bidirectional use cases. The technical specifications of the converter depend, among other things, on the on-board charger as well as the local grid requirements. We see V2G as a critical future use case to be established in the market and rolled out to a large customer base. As technical solutions are only at the beginning and the cost of investment is relatively high, the successful mass adoption of V2G will most likely be a few years from now. There is more work still to be done by authorities to establish a unified certification procedure for a bidirectional charging system.

In summary, the ISO 15118 standard series plays a crucial role in establishing a common and interoperable communication framework for electric vehicles and charging infrastructure (Figure 7). By addressing technical specifications, security considerations, and enabling advanced features like Plug and Charge and vehicle-to-grid capabilities, these series of standards contribute to the widespread adoption of electric vehicles and the development of a more efficient and sustainable transportation ecosystem.

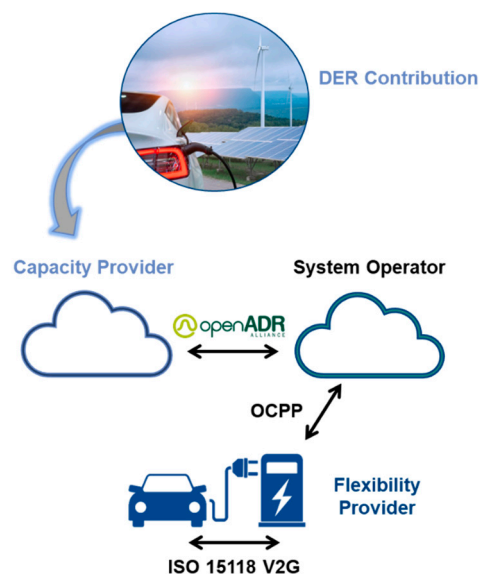


Figure 7. The OCPP and ISO 15118—vehicle-to-grid (V2G)—turn an EV into a mobile and green EES that can contribute energy to the grid in times of high demand and generate an additional financial income stream.

3.3. eRoaming: Charge Anywhere with a Single Mobile App

The idea behind eRoaming is that a driver can “charge anywhere” at any destination charger using only one mobile app. As such, eRoaming contributes to a user-friendly driving experience and is a critical player in achieving EV mass adoption. It has been reported that the download of multiple apps for different destination chargers is one of the most dominant barriers that hinders a driver from purchasing an EV [1].

From a technical perspective, eRoaming requires the integration of a charger’s cloud-based management system into an eRoaming hub or bilateral eRoaming platforms. These platforms store the needed EV certificates and payment options and allow the charger to validate the EV with their database. Globally leading eRoaming hubs include, for example, “e-clearing.net”, “GIREVE”, and “Hubject”, while the “EVRoaming Foundation” supports bilateral webbing as well as the integration with hubs.

3.3.1. Hub-Based eRoaming

The largest hub-based eRoaming structure is Hubject [23]. The network originates from a joint venture between BMW, Bosch, EnBW, Enel X, Mercedes Benz, Innogy, Siemens, and Volkswagen, and is present around the globe, including US, Europe, and China. The roaming hub encompasses more than 300,000 charging stations, leading to a global user base of more than 10 M drivers. To connect a backend to the Hubject network the Open Inter Charge Protocol (OICP) or the Open Charge Point Interface (OCPI) are required.

GIREVE [24] and e-clearing.net [14] are two large European eRoaming hubs, maintaining their respective eRoaming networking protocol, the eMobility Interoperation Protocol (eMIP) and the Open Clearing House Protocol (OCHP), respectively. Both hubs also support the EV Roaming Foundation’s protocol OCPI, which allows OCPI supporters peer-to-peer eRoaming networking as well as hub network relations to GIREVE and e-clearing.net.

3.3.2. Bilateral eRoaming

The non-profit EV Roaming Foundation maintains the free and independent Open Charge Point Interface (OCPI) protocol required to join its network [12]. Members of the global foundation are Google Maps, Last Mile Solutions, Freshmile, and more. The OCPI protocol supports bilateral as well as hub-based roaming. As such, the OCPI supports hybrid eRoaming network structures globally. Service functionalities of the OCPI protocol include authorization, reservation, tariff information, billing, real-time session information, etc. [12].

4. Practical Possibilities and Limitations of the Protocols

This review evaluates the possibilities and opportunities of combining the OCPP with open, cross-functional communication standards, such as the OpenADR, the ISO 15118 standard series, or eRoaming protocols. The goal of standardizing the communication between different players is to solve the major barriers to technical interoperability and capture the opportunities that come with a widespread EV adoption. Current examples of EV charging frustrations are chargers being too slow, too crowded, or not operable [1]. Governmental institutions and funding incentives, such as the National Electric Vehicle Infrastructure (NEVI) Program Formula by the U.S. Department of Transportation’s (DOT) Federal Highway Administration (FHWA), strongly support a unified charging experience through their funding requirements [25].

Interoperability with the leading communication protocol for charger-to-backend communication, the OCPP by the Open Charge Alliance, and the ISO 15118 is a strong first step towards a user-friendly, consistent, and familiar charging experience. In a second phase, the integration of an EV infrastructure into a reliable, smart, and green DER/DR energy ecosystem can be realized by energy communication protocols, such as the OpenADR or OSCP [7,9,10,17].

The improvement of the OCPP relies on open-source development, so the protocol can be continuously updated as lessons are learned from real-world applications. Open-source

application protocols have been proven to provide content that is more correct and reliable than proprietary implementations [16]. We believe the openness of a protocol, paired with the spirit of shared responsibility, will lead to a democratized and fair EV charging infrastructure characterized by high quality, convenience, and reliability. Limitations of the open protocol are the risk of technical interpretation between stakeholders, which have different technical solution approaches. This can lead to implementation friction and delayed roll outs of a standardized infrastructure platform. Testing tools, labs, and events are on the rise to speed up the interoperability process [26].

The OpenADR and OSCP protocols provide a standardized framework for communication between utilities and end users, ensuring interoperability across different systems and devices. This standardization streamlines the implementation of demand response programs. IP-based protocols encompass the capability to support large-scale deployments and the real-time feedback on currently and locally available grid capacity, which allows end nodes to quickly respond to changes in demand and grid conditions [10,16,17]. On the other hand, protocol implementations can be complex and require the orchestration of utilities, aggregators, and end users. Furthermore, the implementation of the protocol on older infrastructure may pose challenges.

Just like any IP-based protocol, the OCPP and the OpenADR rely on internet connectivity, which can be challenging for areas with unreliable or limited internet access. In addition, these protocols might raise security concerns regarding data privacy and network vulnerabilities. It is important to acknowledge that the protocols ensure high-level security mechanisms against cyber threats and are globally established for a safe widespread adoption [7,17].

In bilateral eRoaming agreements, such as the OCPI protocol, network providers and manufacturers sign peer-to-peer agreements to create a web of interoperable chargers. This process can be time- and resource-intensive, and the continuous maintenance of multiple bilateral agreements can introduce novel challenges. In addition, a bilateral roaming solution makes it harder for smaller players to enter the eRoaming market.

In central roaming hub solutions, eMSPs or operators can join an established network in the form of a hub organization. The hub director typically charges a fee for membership, which can potentially be re-directed to the end user. The hub-based eRoaming approach makes it easier for new and smaller players to enter the market against a fee without having to build, accumulate, and manage a large database of EVs and their payment preferences [12,14,23,24].

5. Outlook

Standardized communication in the EV industry enables long-term solutions, along with data sharing and diagnostics to enhance charger availability and uptime. Databases, e.g., the Alternative Fuels Data Center (DOE), display charger locations and availability across the US, fostering charger access and operability information [27]. While availability and downtime minimization are crucial, a standardized shared charger data forum also allows for the analysis of current charger status and consumer behavior, as well as energy usage forecasts, which are particularly important for the aim of fleet electrification (Figure 8).

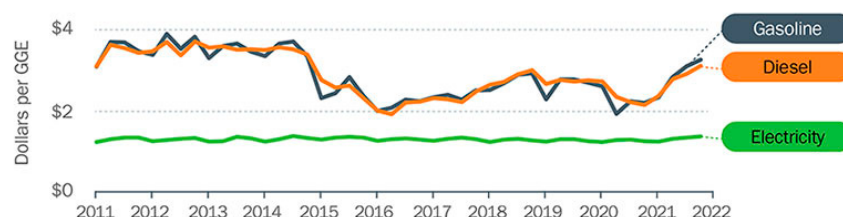


Figure 8. The comparison of electricity prices (USD) with gasoline or diesel shows that the price for electricity is lower and not as fluctuating, which makes it easier to predict costs over time. In addition, EVs offer high propulsion economy, which results in lower operating costs. Reprinted from Ref. [28].

Furthermore, the precise orchestration of energy consumption will be key to the success of mass electrification. Smart charging applications, such as described in the OCPP and OpenADR, allow for load balancing within an EVSE site to minimize energy consumption during peak hours or maximize usage within the limitations of a location's power systems (such as at an apartment building or place of business). Importantly, they can also assist with pushing greater capacity to charging systems when grid capacity is high or supported through active DER contribution, such as solar or wind.

Finally, standardized data sharing supports the development of new energy services and business models such as virtual power plants (VPP) and peer-to-peer energy trading forms.

Global Consortia of public and private EV infrastructure leaders, such as the Open Charge Alliance or the OpenADR Alliance, nurture the development, update, and adaption of international open communication protocols to standardize the EV charging industry and energy ecosystem. The success of a protocol is driven by market dynamics and stakeholder acceptance, together with regulated top-down decision by authorities.

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Conflicts of Interest: Silke R. Kirchner is an employee of Ampure. The paper reflects the views of the author and not the company.

References

1. FACT SHEET: Biden-Harris Administration Announces New Standards and Major Progress for a Made-in-America National Network of Electric Vehicle Chargers. Available online: <https://www.whitehouse.gov/briefing-room/statements-releases/2023/02/15/fact-sheet-biden-harris-administration-announces-new-standards-and-major-progress-for-a-made-in-america-national-network-of-electric-vehicle-chargers/> (accessed on 11 February 2023).
2. The Expanding EV Market, Observations in a Year of Growth. Plug in America. Available online: <https://www.atlasevhub.com/resource/the-expanding-ev-market-observations-in-a-year-of-growth/> (accessed on 15 February 2023).
3. What Is EV Charging Anxiety—And Is Range Anxiety a Thing of the Past? Available online: <https://www.nationalgrid.com/group/what-ev-charging-anxiety-and-range-anxiety-thing-past#:~:text=Simply%20put,%20range%20anxiety%20is,be%20few%20and%20far%20between> (accessed on 23 January 2023).
4. Kirchner, S.R.; Ruiz, H. OCPP Interoperability: Democratized Future of Charging. In Proceedings of the 36th International Electric Vehicle Symposium and Exhibition, Sacramento, CA, USA, 11–14 June 2023; pp. 1–12.
5. What Are LoRa and LoRaWAN? Available online: <https://www.thethingsnetwork.org/docs/lorawan/what-is-lorawan/> (accessed on 13 February 2023).
6. What Are LoRa® and LoRaWAN®? Available online: [https://lora-developers.semtech.com/documentation/tech-papers-and-guides/lora-and-lorawan/#:~:text=The%20name,%20LoRa,%20is%20a,areas%20\(line%20of%20sight](https://lora-developers.semtech.com/documentation/tech-papers-and-guides/lora-and-lorawan/#:~:text=The%20name,%20LoRa,%20is%20a,areas%20(line%20of%20sight) (accessed on 11 February 2023).
7. Open Charge Point Protocol 2.0.1. Available online: <https://openchargealliance.org/protocols/open-charge-point-protocol/> (accessed on 23 January 2023).
8. OpenADR Alliance. DER Control and How to Implement Smart Inverter Management with OpenADR. Available online: https://www.openadr.org/assets/OpenADR%20for%20Smart%20Inverter%20Control_final.pdf (accessed on 15 February 2023).
9. Open Smart Charging Protocol. Available online: <https://openchargealliance.org/protocols/open-smart-charging-protocol/> (accessed on 27 March 2023).
10. ISO 15118; Road Vehicles—Vehicle to Grid Communication Interface. International Organization for Standardization: Geneva, Switzerland, 2019.
11. Open Plug&Charge Protocol. Available online: <https://github.com/hubject/opcp> (accessed on 23 February 2023).
12. EVRoaming Foundation. Available online: <https://evroaming.org/about-us/> (accessed on 1 March 2023).
13. Gireve, eMIP Protocol. Available online: https://www.gireve.com/wp-content/uploads/2022/09/Gireve_Tech_eMIP-V0.7.4_ProtocolDescription_1.0.14-en.pdf (accessed on 27 March 2023).
14. e-clearing.net. Available online: <https://e-clearing.net/> (accessed on 2 February 2023).
15. U.S. Grid Energy Storage Factsheet. Available online: <https://css.umich.edu/publications/factsheets/energy/us-grid-energy-storage-factsheet> (accessed on 27 March 2023).
16. McParland, C. OpenADR Open Source Toolkit: Developing Open Source Software for the Smart Grid. In Proceedings of the 2011 IEEE Power and Energy Society General Meeting, Detroit, MI, USA, 24–28 July 2011.
17. OpenADR. Connecting Smart Energy to the Grid. Available online: <https://www.openadr.org/> (accessed on 15 February 2023).

18. Burlig, F.; Bushnell, J.; Rapson, D.; Wolfram, C. Low Energy: Estimating Electric Vehicle Electricity Use. *AEA Pap. Proc.* **2021**, *11*, 430–435. [CrossRef]
19. Draz, M.; Kleeberg, T.; Vahrenholz, C.; Stichtenoth, F.; Deliverable 4.1 Plug & Charge Guidance Document. echarge4drivers. 2021. Available online: <https://zenodo.org/records/6855650> (accessed on 27 March 2023).
20. Was Ist Die ISO 15118? Available online: <https://www.tuev-nord.de/explore/de/erklaert/was-ist-die-iso-15118/#:~:text=Die%20ISO%2015118%20gew%C3%A4hrleistet%20dabei,Vertragsdaten%20der%20Nutzenden%20gesch%C3%BCtzt%20sind> (accessed on 25 January 2023).
21. Electric Car Battery Basics: Capacity, Charging and Range. Available online: <https://www.edmunds.com/car-technology/electric-car-battery-basics-capacity-charging-and-range.html> (accessed on 24 January 2023).
22. What's the Average Home Energy Consumption in Your State? Available online: <https://majorenergy.com/whats-the-average-home-energy-consumption-in-your-state/> (accessed on 11 February 2023).
23. Hubject. Available online: <https://www.hubject.com/> (accessed on 20 January 2023).
24. Gireve Powering New Mobilities. Available online: <https://www.gireve.com/> (accessed on 25 January 2023).
25. U.S. Department of Transportation. Available online: https://www.fhwa.dot.gov/bipartisan-infrastructure-law/nevi_formula_program.cfm/ (accessed on 19 April 2024).
26. Open Charge Alliance. Available online: <https://openchargealliance.org/save-the-date-ocpp-plugfest-around-the-globe/> (accessed on 19 April 2024).
27. Alternative Fuels Data Center. Available online: <https://afdc.energy.gov/> (accessed on 20 January 2023).
28. U.S. Department of Energy. Available online: https://afdc.energy.gov/vehicles/electric_fleets.html/ (accessed on 21 December 2023).

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