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EV Charging Needs, Challenges and Opportunities

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TITLE

EV Charging Needs, Challenges and Opportunities from a global perspective

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All the pictures are provided by the SOL+ partner

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

TABLE OF ABBREVIATIONS

AC	Alternating Current
ACD	Automated Connection Device
AFIR	Alternative Fuels Infrastructure Regulation
BEV	Battery Electric Vehicle
CaaS	Charging as a Service
CAPEX	Capital expenditure (per vehicle)
CCS	Combined Charging System
CO2	Carbon dioxide
CPO	Charging Point Operator
DC	Direct Current
DER	Distributed Energy Resources
DSO	Distribution system operator
DV	Heavy-duty vehicle
EMC	Electro-Magnetic Compatibility
ERTICO	European Road Transport Telematics Implementation Coordination
ESP	Engineering Services Provider
EU	European Union
EV	Electric vehicle
EVCI	Electric vehicle charging infrastructure
EVSE	Electric vehicle supply equipment
GHG	Greenhouse gas
GPS	Global Positioning System
HDV	Heavy-duty vehicle
ICEV	Internal combustion engine vehicle
IDIADA	Institut d'Investigació Aplicada de l'Automòbil (Institute for Applied Automotive Research)
IEA	International Energy Agency
IEC	International Electrotechnical Commission
MSP	Mobility service provider
NOx	Nitrogen Oxides
OCPP	Open Charge Point Protocol
OEM	Original equipment manufacturer
PPP	Public-private partnership
SAE	Society of Automotive Engineers
SOL+	SOLUTIONSplus
SotA	State of the Art
TCO	Total cost of ownership
TSO	Transmission System Operators
V2G	Vehicle-to-grid
ZEV	Zero-emission vehicle

EXECUTIVE SUMMARY

This report aims to shed light on electric vehicle (EV) charging needs, challenges and opportunities and examines the critical role of charging infrastructure in facilitating the widespread adoption of electric vehicles (EVs). While EVs offer environmental benefits, their success hinges on overcoming challenges related to charging accessibility, speed, and reliability.

The report analyses diverse charging needs across vehicle types and usage patterns, emphasizing the importance of interoperability and standardization. It explores the complex interplay of stakeholders, including governments, industry, and consumers, in shaping the charging ecosystem.

By identifying key challenges and opportunities, this report provides insights for policymakers and industry leaders to develop effective strategies for deploying and managing charging infrastructure. Ultimately, the goal is to create a charging network that supports seamless EV integration and contributes to a sustainable transportation future.

INTRODUCTION

The transition to electric vehicles (EVs) holds immense potential for reducing carbon emissions in urban environments. Governmental policies aimed at reducing greenhouse GHG emissions around the globe usually promote fleet electrification as one way of helping achieve their targets, with tax incentives commonly proposed with the goal of accelerating the transition from internal combustion engine vehicles (ICEVs) to EVs.

However, widespread EV adoption is hampered by the suboptimal availability and location of charging stations. Range anxiety, or the fear that the vehicle's range will be insufficient to cover the distance to a desired destination, is a significant barrier to the deployment of EVs, which can be overcome by the increased availability of charging infrastructure (Transportation Research Board and National Research Council, 2015). Hence, widespread EV adoption hinges on the development of robust and efficient charging infrastructure.

The SOLUTIONSplus project aims to enable transformational change towards sustainable urban mobility through innovative and integrated electric mobility solutions. It is funded under the European Union's Horizon 2020 and encompasses city-level demonstrations, testing innovative e-mobility solutions and charging infrastructure, and capacity-building and replication activities in established and emerging economies across Europe, Asia, and Latin America.

Taking insights from the SOLUTIONSplus cities, this report aims to identify various needs, challenges and opportunities associated with EV charging. It offers a comprehensive overview of the current electric vehicle charging infrastructure (EVCI) landscape and examines the key trends, challenges, and opportunities affecting the implementation of EVCI.

The first part of this report discusses the foundational elements of EVCI development. By examining the evolution of charging infrastructure, the complexities of interoperability and standardization, it offers a nuanced understanding of the factors driving EV adoption and the barriers hindering its widespread implementation.

The second part of this report deepens the analysis by adding relevant input from SOLUTIONSPlus cities and other global market leaders. Furthermore, it focuses on region-specific needs, challenges, and opportunities for EVCI. It identifies critical infrastructure gaps and proposes actionable recommendations to address them. By understanding the unique characteristics of different regions, this report aims to inform policymakers, industry stakeholders, and investors in developing effective EVCI solutions that accelerate the transition to electric mobility.

The Charging Ecosystem

1. THE CHARGING ECOSYSTEM

The successful adoption of electric vehicles (EVs) is inextricably linked to the development of a robust and accessible charging infrastructure. To support this transition, it is essential to understand the current charging ecosystem and its components. This chapter dives into the intricate ecosystem surrounding EV charging, examining the various stakeholders, technologies, and business models that collectively shape the charging sector. From the design and deployment of charging stations to the integration of charging networks with the broader energy grid, as well as ensuring interoperability and standardization, this chapter explores the critical components necessary to support the widespread adoption of electric vehicles.
Before delving into the components and intricacies of the EV charging ecosystem, it is essential to recognize the diverse stakeholders involved. This complex network includes an array of actors, as described below, and the interplay between these actors significantly influences the development, deployment, and utilization of charging infrastructure.

1.1. Key Stakeholders in the EV Charging Sector

Public agencies

European institutions such as the European Commission and the European Fuel Observatory play a pivotal role in shaping the EV charging landscape. By providing funding, setting standards, and conducting research, these agencies foster a conducive environment for EV adoption. Their efforts in establishing common technical frameworks and promoting interoperability are essential for the seamless integration of charging infrastructure across Europe.

Industry Stakeholders

Vehicle Manufacturers (OEMs) and Suppliers *play* a critical role in developing EV charging technologies that align with international standards, prioritizing interoperability from the outset. Their involvement in standardization committees is essential for ensuring compatibility and facilitating market growth.

Electricity Market Stakeholders i*ncluding* energy ministries and providers, are instrumental in shaping supportive policies for EV charging infrastructure. Promoting competition while preventing market dominance is crucial for ensuring fair pricing and service quality.

Engineering Service Providers offer expertise in interoperability testing and development, helping to streamline the integration of charging equipment and vehicles. Their collaboration with OEMs and charging infrastructure manufacturers is vital for accelerating technology adoption.

Ecosystem Stakeholders

Public Transport Operators benefit from efficient and reliable charging infrastructure through reduced operational costs and increased service reliability. Interoperability enables fleet operators to optimize charging strategies and reduce dependency on specific suppliers.

Energy Distribution System Operators play a crucial role in grid management by leveraging charging infrastructure for demand response and grid stabilization. Accurate load forecasting and efficient energy distribution are essential for integrating EVs into the power system.

End-Users

EV Drivers: As the final consumers, EV drivers are central to the success of the charging ecosystem. Their satisfaction with charging availability, speed, and cost directly impacts market adoption. Understanding driver's behaviour, charging patterns, charger preferences (Public or Private Chargers), etc. are essential for tailoring charging solutions to meet user needs.

1.2. Basic Definitions related to EVCI

To fully understand the intricacies of EV charging infrastructure, a clear definition of its core components is essential. The following section outlines the key elements that comprise the EV charging ecosystem.

Charging Pool

A charging pool comprises one or more charging stations along with their associated parking spaces. These are managed by a single charge point operator (CPO) at a specific location identified by its address and GPS coordinates. The charging pool serves as a mapping reference and includes all features necessary to represent a charging infrastructure element on a map.

Charging Station / Charging Pole / Charging Dock / Electric Vehicle Charging Station (EVCS)

A charging station is a physical unit equipped with one or more charging points and a common user interface. This interface may include elements such as badge readers, buttons, displays, or LEDs for user interaction. Some charging stations operate on a "Plug & Charge" basis, automatically identifying vehicles without requiring manual input. Each charging station corresponds to one physical object and one user interface.

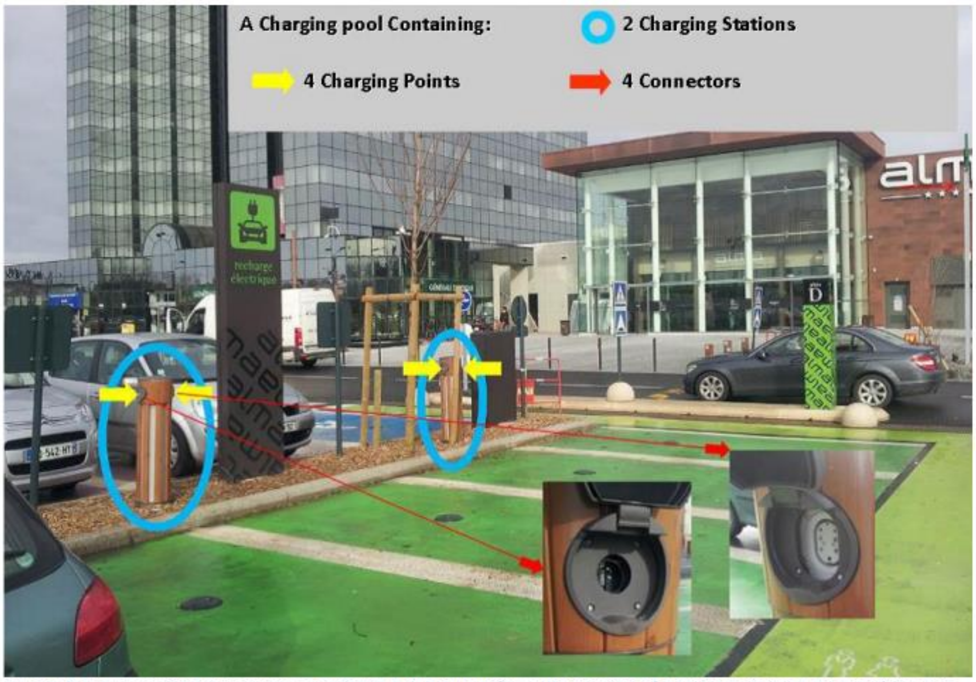
Charging Point / Charging Position / Electric Vehicle Supply Equipment (EVSE)

The electric energy is delivered through a charging point, which may feature one or multiple connectors to accommodate different plug types. However, only one connector can be used at a time per charging point, corresponding to one vehicle being charged simultaneously.

Connector

This is the physical link between the charging station and the electric vehicle, facilitating the delivery of electric energy. Connectors can take various forms, such as plugs on cables, plugs attached to inseparable cables of the charging station, induction plates, or pantographs. The number of connectors typically corresponds to the number of charging points, although there may be exceptions, such as charging stations with more connectors than charging points.
In summary:

- A charging pool may contain multiple charging stations.
- A charging station may contain multiple charging points.
- A charging point may contain multiple connectors.
- Only one connector per charging point can be active for EV recharging at a time.



Source: STF: Sustainable Transport Forum, SGEMS: Sub-Group to foster the creation of an Electro-mobility Market of Services

Figure 1 Charging Station Overview

A recharging pool must include:

- A minimum of 1 recharging station
- At least 1 recharging point
- A minimum of 1 connector

In Figure No. 1 the total breakdown is as follows:

- 1 recharging pool
- 3 recharging stations
- 6 recharging points
- 12 connectors

AC and DC Charging

Box No. 1: AC and DC Charging

Electric mobility relies on two primary types of electrical currents for charging EVs: AC (alternating current) and DC (direct current). In the charging infrastructure landscape, AC is predominantly used in home EV chargers and some public charging stations, whereas DC is employed for fast charging purposes.

Direct current (DC) is an electrical current or flow of charge that flows steadily in one direction, like the constant flow of a river. It's like the electricity from batteries and solar cells, where the energy moves consistently. On the other hand, alternating current (AC) switches between positive and negative sides, creating a fluctuating flow that changes direction. This is how electricity is typically sent from power plants to homes. DC keeps a steady voltage and flow, while AC varies its voltage, causing the current to change direction periodically. The following figure illustrates the difference in the current methodologies:

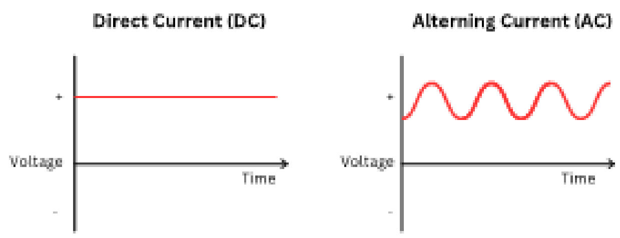


Figure 2 AC and DC Current

Main distinction between AC and DC charging

A distinction between AC and DC lies in where AC power is converted to DC power either inside or outside the vehicle. When utilizing a DC charging station, the conversion from AC (from the grid) to DC occurs within the station itself, enabling direct flow of DC power from the station into the EV battery. Since the conversion process takes place within the charging station rather than the EV, DC chargers, typically are larger due to the onboard converter and more robust converters can be employed to rapidly convert AC from the grid. In the case of AC chargers, the conversion process initiates within the vehicle itself. EVs come equipped with an onboard converter.
AC charging stations directly supply AC power to EVs, typically with lower capacities and compact dimensions. These chargers usually provide up to **22 kW** of power. On the other hand, DC charging stations convert AC from the grid to DC, resulting in larger charger sizes that often require (air or liquid) cooling facilities. However, DC chargers offer higher capacities, with some capable of delivering up to **400 kW** of power. Additionally, new technologies deliver even higher capacities on DC chargers up to 1 MW.
While AC charging is commonly employed for home EV chargers and most public charging stations, DC charging is preferred for fast charging scenarios. Despite its speed advantages, DC charging requires larger and more expensive equipment, along with a medium- or high-voltage connection to the power grid, making it impractical for home installations.

Charging Levels

Charging levels categorize the different types of charging infrastructure available for EVs, based on the power output and speed of charging. There are typically four charging levels, each offering varying degrees of power delivery and charging times.

Table 1 Overview of Charging Levels

Charging Type	Speed	Type of Location	Duration (hours)	Typical Power
Level 1 AC	Low	Households	4 to 36 hours	1.90 – 7.40 kW
Level 2 AC	Rapid	Households, workplaces, parking lots, retail stores, supermarkets, hotels, overnights charging.	2 to 13 hours	7,40 -22 kW
Level 3 DC	Fast	Designated parking lots, highway stop areas	15 min to 2 hours	22 - 350 kW
Level 4 DC	Ultra Fast	Designated parking lots, highway stop areas	5 min to 2 hours	> 350Kw

Charging Connectors

A variety of charging connectors have emerged as regional standards over the past decade. As illustrated in the following figure, different regions have adopted specific connector types. Regions that are not mentioned in the figure, usually adopt at least one of the available standards as the default, depending on the origin of imported new and used cars.

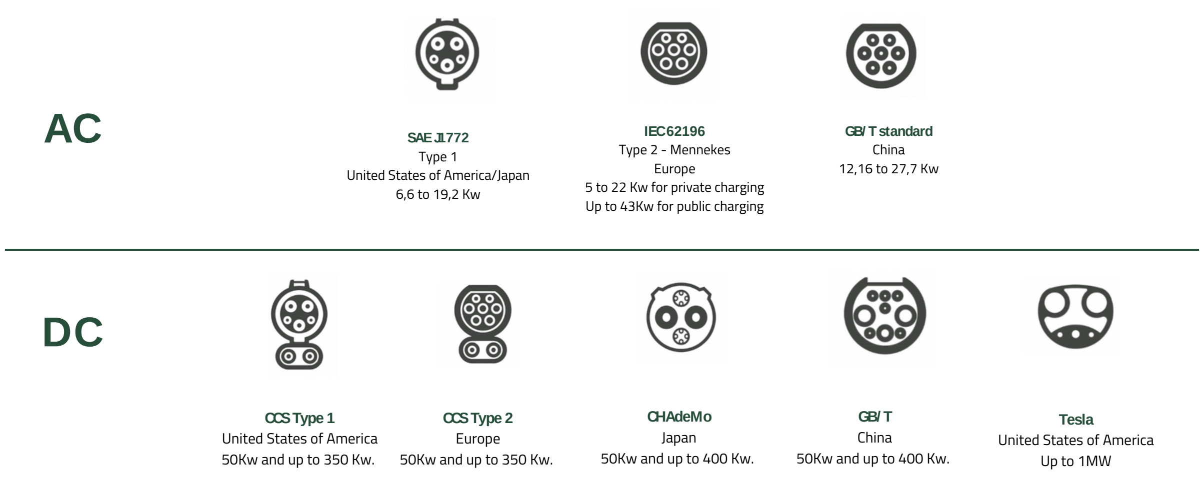


Figure 3 Type of EV connectors

Source: (Analysis Report of Charging Ecosystem in Partner Regions, 2024)

The following table provides a description of each of the main types of connectors used in the market.

Table 2 Overview of connector types

Source: Analysis Report of Charging Ecosystem in Partner Regions

Type of Connector	Explanation
AC Connectors	
 **AC – SAE J1772 (Type 1) USA/ Japan**	The J1772 connector, initially created by Yazaki and commonly referred to as Type 1, has found extensive usage in North America and Asia. Specifically designed for AC charging, it accommodates power ratings ranging from 6.6 kW to 19.2 kW. Renowned for its compatibility with a vast majority of electric vehicles in the United States and Asia, the J1772 connector continues to be a preferred option for both residential and public charging infrastructure.
	The Mennekes connector, also known as Type 2, stands as a prominent European standard plug extensively utilized throughout Europe, particularly for AC charging applications. With power delivery capacities ranging from 12 kW to 22 kW for private charging and reaching up to 43 kW for public charging, the Type 2

AC – IEC 62196 Mennekes (Type 2) Europe	connector offers versatility and reliability. Noteworthy for its ergonomic design and integrated automatic locking mechanism, this connector guarantees secure and efficient charging operations for electric vehicle owners across the continent.
 **AC - GB/T standard Connector China**	The GB/T connector, developed by the Guobiao Standardization Commission, stands as the primary AC charging plug within China, representing the country's dominant standard for electric vehicle charging. Supporting power ratings of up to 27.7 kW, this connector accommodates the expanding fleet of electric vehicles within the world's largest automotive market. Despite its visual resemblance to the Type 2 connector, the internal wiring of the GB/T connector sets it apart, rendering it incompatible with European standards.
DC Connectors	
 **CCS - Type 1 USA**	The Combined Charging System (CCS), Type 1, offers a solution for rapid DC charging. In this approach, the lower pins directly facilitate charging, while the upper part's communication pin and ground conductor serve as reference points for protection systems. These connectors support power levels of up to 350 kW and can handle voltages ranging from 200 V to 1 kV at up to 350 A. One significant advantage of the CCS connector is its capability to perform both AC and DC charging simultaneously. These connectors comply with various standards, including IEC 62196–1, IEC 62196–2, and IEC 62196–3. ChargeIN oversees the adoption and standardization of Combo-type connectors.
 **CCS - Type 2 Europe**	The CCS Type 2, a fast DC charging system commonly used in Europe, is regulated by ChargeIn and boasts a power capacity of up to 350 kW. Its widespread adoption can be attributed to the convenience of having a single socket. However, it's important to note that CCS connectors are incompatible with CHAdeMO and GB/T charging stations due to variations in communication protocols. This disparity often requires the use of specialized adapters, which may be challenging to obtain
 **CHAdeMo Japan**	The CHAdeMO connector, developed by the Japan EV Association, emerges as a prominent DC charging plug predominantly utilized by Japanese automakers. Renowned for its rapid charging capabilities, CHAdeMO connectors can deliver power up to 400 kW, facilitating swift charging experiences and enjoying widespread adoption across Asia. However, despite its initial dominance, the CHAdeMO standard encounters stiff competition

	from CCS connectors in regions like Europe and North America. This competition has resulted in a gradual decline in the prominence of the CHAdeMO standard as other charging standards gain traction in these markets.
  **Tesla Connector (NACS): USA**	Initially exclusive to Tesla vehicles, Tesla's proprietary charging connector, known as the North American Charging Standard (NACS), represented a hallmark feature of Tesla's charging infrastructure. With remarkable power delivery capabilities of up to 1 MW, NACS connectors enable rapid charging, a key factor in Tesla's extensive charging network's efficiency. However, in a strategic shift towards standardization and interoperability, Tesla has embraced CCS2 connectors for its vehicles in Europe. This move aims to facilitate seamless compatibility with non-Tesla charging stations across the continent, ensuring convenience for Tesla owners and promoting broader adoption of electric vehicles.

Megawatt Charging

The Combined Charging System (CCS) has had an important position as a standard due to its versatility and compatibility with different vehicle types. However, CCS has its own limitations for Heavy Duty Vehicles (HDVs), since they require considerably more power than standard vehicles. To accommodate these high-capacity needs, the Megawatt Charging System (MCS) is a new standard designed for high-power applications. While CCS is being used for passenger vehicles and some commercial vehicles, MCS is emerging for heavy-duty vehicles, en-route charging and other electric heavy modes of transportation.

This initiative is under the coordination of ChargeIN and provides heavy-duty trucks with a charging capacity of 4.5 MW. Voltage will range between 500-1250V, and the current has been tested until 3000A. It is, therefore, a very important step towards the future of heavy-duty charging and other high-capacity modalities such as marine and aviation electric transportation. The MCS concept, as described by ChargeIN, ranges beyond a charging system and connector but includes recommendations on, e.g. location aspects (‘drive-through charging’) and software standards (OCPP, ISO15118) etc (*Megawatt Charging System (MCS)*, 2024). The MCS includes features such as the connector shape, communication electronic, increased current capacity and voltage level.

Figure 4 Megawatt Charging Plug Layout

Source: CharIN e. V. MCS Subgroup, 2022

1.3. Stakeholders and Business Models

In addition to the physical elements discussed in the previous sections, the following stakeholders and service providers come together to make a charging infrastructure work efficiently:

Charge Point Operator – (CPO)

The CPO oversees the installation, management, maintenance, and operation of charging stations, handling both technical and administrative aspects. The CPO's role may be divided into administrative responsibilities (e.g., access control, billing) and technical maintenance, which is often outsourced to the manufacturer. The CPO is usually also the registered entity of the grid connection and, therefore, maintains a close relationship with the distribution system operator and the meter operator.

Charge Location Owner

The charge location owner possesses ownership of the charging location and often the charging point itself. Depending on whether the location is public or private, the energy may be procured by the charge location owner or the charge point operator.

Mobility Service Provider (MSP or eMSP)

The electric-Mobility Service Provider is the entity with which the EV driver enters into a contract for services related to the EV operation. Typically, the MSP performs services and/or integrates services from other market actors, such as access to charging networks, navigation, payment, parking, or smart charging services. Car manufacturers or utilities may also fulfil this role. In order to provide these services, roaming contracts and operational (data) interfaces are required.

Roaming Platform and Aggregator

A roaming platform or aggregator serves as a central organization facilitating information exchange among multiple market players in order to allow roaming. It connects different market participants to establish a digital and cross-border charging network for electric vehicles. Different variants exist as to the number of services provided.

Energy Supplier

The energy supplier provides the electricity for electric vehicles via the grid connection of the (public or private) charging points. Various suppliers produce or purchase energy for this purpose. The CPO or location owner is usually considered the customer of the energy supplier, amongst others, depending on aspects such as whether the charging point is public or private, the market model or the contractual agreement.

Distribution System Operator (DSO) or Regional Grid Operator:

The DSO designs, operates, and maintains the public distribution medium- and low-voltage grid, which supplies power to the grid connection. The charging locations are either directly connected to the grid connection or are part of a private grid (e.g., home, building) connected to the DSO grid.
The primary focus of the DSO is to ensure the availability of electricity at every moment, assure power quality and prevent issues such as grid congestion and disruptive events.

Transmission System Operator (TSO)

The TSO is responsible for maintaining stable power system operation, including physical balance, through a high-voltage transmission grid within a geographical area. Additionally, the TSO determines and manages cross-border capacity and exchanges, adjusting allocated capacity as needed to ensure operational stability.

1.3.1. Leading CPO in the US and EU

In each country and region, the electric mobility value chain has developed differently. The same holds for charging infrastructure.

United States

In the US, startups such as Tesla, ChargePoint, EVGo and Greenlots have been instrumental in the inception and growth of a mature charging infrastructure network, while public utilities have taken up a less visible role in the beginning.

In Europe and Latin America however, the incumbent network of energy utilities (DSOs) has played a dominant role in the uptake of charging infrastructure.

European Union

The European Commission provides guidance through the AFIR regulation, with additional work being performed in the Strategic Transport Forum, thus providing a platform for harmonization either through regulation, policy, contracting requirements or recommendations. However, differences in opinion remain as to what level of harmonization and standardization should be prescribed to harmonize market models and provide the optimal conditions for scale-up and user satisfaction. Below, some fundamental conditions for harmonization are considered.

Also, within Europe, each country has developed a different market model driven by the historical context (current energy and transport market models), local context (e.g. level of urbanization, current modes of transport) and policy choices (e.g. the role of government in a market-driven context).

Two examples illustrate the current differences in approach in Europe:

Portugal

The market model for publicly accessible EV charging infrastructure in Portugal is coordinated by MOBI.E as mandated by the Portuguese central government. Every operator (CPO) and every service provider (EMSP) that wants to enter the Portuguese market for EV charging, will need to register with MOBI.E. Every charging station manufacturer needs to be certified against the MOBI.E requirements. These market players must confirm to specific functional and technical requirements that, amongst others, assure full interoperability and transparent pricing. Although an open market, there is a strong central coordination to assure standardization, compliance and a user centric approach.

Germany

The market for publicly accessible EV charging infrastructure in Germany comprises a wide range of diverse participants, both from private and public origin, including utilities such as E.on, RWE, EnBW, Vattenfall and many smaller regional ‘Stadtwerke’. There are approximately 900 Stadtwerke in Germany, bringing forth approximately 150 utility companies (Wagner et al., 2021). Further stakeholders are automotive companies (Audi, Volkswagen, Tesla), petrol stations (Aral Pulse, Shell Recharge), and independent charging point operators (Ionity, Fastned). National regulation describes certain technical requirements and protocols, such as OCPP, but there is no formal regulatory framework in place to assure full interoperability, roaming or otherwise organize collaboration between market actors.

1.4. Business models for EV charging infrastructure

Mobility as a Service (MaaS)

Mobility as a Service (MaaS) is an innovative model in which people purchase transportation services instead of owning private vehicles. This model integrates various modes of electric transportation, such as EVs, electric-scooters and electric-bikes, into a cohesive service. The vehicles and their charging infrastructure are owned by a third party and rented out to users, who pay for the transportation services they use. MaaS promotes the use of electric commercial fleets and offers a flexible and sustainable alternative to vehicle ownership (*E-Mobility as a Service*, 2022).

Shared vehicles in the E-MaaS model typically have higher utilization rates than privately owned vehicles, reducing the overall costs of EVs and accelerating the transition to electric mobility. Additionally, Vehicle-to-Grid (V2G) technology enables MaaS operators to generate additional revenue by providing services to the electrical grid (Afentoulis et al., 2022).

Charging as a Service (CaaS)

Charging as a Service (CaaS) transforms the EV industry by allowing EV owners to charge their vehicles without needing to own or manage a charging station. In this model, a third-party company owns and operates the charging infrastructure, offering a comprehensive service package that includes hardware, billing, maintenance, and support. Payment options are flexible, including contracts or pay-as-you-go arrangements with fixed or variable rates. CaaS providers can be retailers, municipalities, or businesses with parking facilities for guests and employees (*EV Charging as a Service*, 2022).
An EV CaaS provider oversees every aspect of the charging infrastructure. This includes project planning, station management, and ongoing maintenance, all for a predictable monthly or annual fee. This arrangement allows companies to focus on their core operations while benefiting from a hassle-free and cost-effective EV charging solution (*EV Charging as a Service (CaaS)*, 2023).
EV CaaS providers are responsible for:

- Managing all project management and installation activities.
- Operating and maintaining the EV Charging Management System (CMS).
- Ensuring smooth operations and providing maintenance services.
- Handling customer interactions and support.
- Offering 24/7 support and security.

Ownership and Operation of Public Charging Stations

Innovative business models for the ownership and operation of public charging stations are emerging. These models include gas stations adding EV chargers, EV chargers managed and owned by energy retailers, DSOs, or charging point operators, and commercial businesses expanding their services by incorporating EV chargers. Charging stations can be owned by various entities, including technology companies, utilities, governments, municipalities, or other retailers. These innovative approaches to the ownership and operation of public charging stations make public charging more accessible, thereby facilitating the faster adoption of EVs. By integrating these models, businesses can offer public charging services that not only enhance accessibility but also contribute to a sustainable and efficient transportation ecosystem.

EV Aggregators

Electric Vehicle Aggregators play a crucial role in integrating EVs into the power grid and provide multiple benefits to the grid by combining various Distributed Energy Resources (DERs) and operating them as a single entity, such as a virtual power plant. These benefits include load shifting, balancing for Transmission System Operators (TSOs), and offering local flexibility for Distribution System Operators (DSOs) (*EV Aggregators*, 2022).

Electric Vehicle Aggregators exploit the flexibility potential of smart charging by optimally managing the complex process over a distributed network of connected charging stations. Smart charging allows the charging cycle of an EV to be adjusted based on external events, enabling adaptive charging habits. The viability of EVA businesses depends on several factors:

- EV Flexibility Potential: The amount of flexibility that EVs can provide.
- Market Regulatory Framework: The regulations governing the market.
- Stakeholder Interactions: The relationships between various stakeholders in the e-mobility ecosystem.
- Participation Willingness: The willingness of Electric Vehicle Users to engage in Demand Response programs.

Maximizing Value through Aggregation

A single EV cannot significantly participate in markets or provide grid services alone. However, a pool of EVs can offer substantial benefits and enable new business models. Aggregators can stack various services from EVs to extract more value from multiple revenue streams. Additionally, they can combine pools of EVs with other assets, such as stationary batteries or controllable loads, to maximize value.

By pooling EV resources and managing their smart charging capabilities, Electric Vehicle Aggregators help balance the grid, improve energy security, and create new revenue opportunities, thereby playing a critical role in the transition to a more sustainable and resilient energy system.

Integration of EV Charging Infrastructure with DERs

EV charging infrastructure can be effectively combined with solar energy systems, energy storage, or other on-site Distributed Energy Resources (DERs). This combination is particularly beneficial for various charging stations, including those on highways, in cities, at bus depots, and for electric truck charging. Additionally, it supports charging in off-grid areas or regions with weak grid connections. The most common installations pair EV chargers with solar photovoltaic systems, typically implemented as solar rooftops or canopies (*Shaving of EV Peak Loads Using DERs*, 2022).
Integrating EV chargers with DERs offers several advantages:

- Reduction of Peak Loads: Charging EVs with DERs helps to shave peak loads and reduce congestion on the grid.
- Maximized Use of Generated Energy: Plugged-in EVs can absorb electricity generated from DERs that might otherwise go to waste due to a lack of immediate demand.
- Avoidance of Grid Investments: This approach eliminates the need for substantial distribution investments and grid capacity expansions required to supply large amounts of power to traditional grid-connected charging stations.

- Support for Off-Grid Charging: Off-grid solar charging systems are particularly advantageous in regions with weak grids, as they facilitate the transition to electric mobility without the need for extensive network extensions.

By leveraging DERs, the integration of EV charging infrastructure becomes more efficient, sustainable, and resilient, promoting a faster adoption of electric vehicles and reducing the strain on existing power grids.

Battery Swapping

Battery packs are the most expensive component of EVs, representing about one-third of the total cost of the vehicle, and they degrade over time. Battery swapping offers an alternative to traditional charging by replacing empty battery packs with fully charged ones. This method requires battery packs to be easily accessible and replaceable, making it particularly suitable for lightweight vehicles such as electric two- and three-wheelers. For heavier vehicles, battery swapping can be more complex, often requiring a mechanic's assistance (*IRENA, Battery Swapping*, 2022) .

1.5. Interoperability, standardization and roaming.

Harmonization across market models

The EV charging landscape has evolved rapidly, with diverse market models emerging across the globe. Each region presents unique characteristics in terms of regulations, roles and responsibilities, market openness, and financial incentives. Europe, for instance, showcases a variety of approaches, from tightly regulated to more market-driven models.
Within these varying market structures, both public and private entities are actively involved in driving innovation and improvement. The EV charging sector is a dynamic blend of transportation, energy, urban planning, and digital technologies, requiring a holistic approach to address its complexities.

The concept of Interoperability

Interoperability is a concept that refers to the ability of systems or actors to operate together. The International Organization for Standardization (ISO) in its standard ISO/IEC 2382-01 (Information Technology Vocabulary, Fundamental Terms), defines interoperability as "the capability to communicate, execute programs, or transfer data among various functional units in a manner that requires the user to have little or no knowledge of the unique characteristics of those units". On the other hand, the Intelligent Transport Systems directive of the European Commission (ITS 2010/40/EU) defines interoperability as "the capacity of systems and the underlying business processes to exchange data and to share information and knowledge".

Interoperability as a concept has been successful in sectors like telecommunications and IT. The benefits of interoperability include:

- Reduction of installation and integration costs.
- with limited dependencies on third parties.
- A better competitive environment as technology 'lock-in' is prevented, there is an equal playing field, resulting in a better comparison of offerings.
- A shift of competition towards price and reliability because the (price) transparency in an equal playing field makes it possible to provide more advanced offerings.

An open market for electric vehicle charging and 'layers of interoperability'

In the context of EV charging, an open, market-driven sector relies on both interoperability and openness. Each country or region may define which part of the sector is competitive and which is considered pre- or non-competitive

The Smart Grid Architecture Model, developed by the European standardization organization CEN-CENELEC, identifies different 'layers of interoperability' needed for a successful market-driven sector, including:

- Hardware layer focuses on interoperability of connectors and plugs.
- Communication layer involves seamless communication between hardware and software systems to exchange data, similar to an IP or 4G protocol.
- Information layer, the information that is being exchanged needs to be recognized and interpreted through a standardized data model and information protocols.
- Service layer, requires standardization and interoperability to allow for predictable and measurable services such as payment, roaming, navigation and reporting.
- Business layer, necessitates a non-discriminatory regulatory framework to describe the 'rules of the game', and standardized contracting arrangements between market actors to ensure predictability and sustainability on aspects such as settlement, liability, disputes, etc.

The degree of interoperability may vary per market, but a certain level is necessary to achieve mature user-centric service definitions (on themes such as pricing, navigation, payments, and roaming) and efficient back-end processes for the installation and operation of charging infrastructure, making use of different manufacturers, operators, DSO's and construction companies.

Direct payment, subscriptions and EV Roaming

The deployment of charging infrastructure has started with (CPOs) offering access to their charging networks through either a direct payment or a subscription-based (post-payment) model. With the emergence of a market-driven operational model and multiple CPOs providing charging services, the role of an (eMSP) has been defined to offer EV drivers mobility services across multiple CPO networks. These services include navigation, information, charging access, payment, invoicing, and more. It is worth noting that each CPO can also function as an eMSP, providing services that span all third-party charging networks.

Direct payment

Direct payment solutions utilize existing interoperable payment systems such as credit card terminals, QR codes, and in-app payments. Like payment at petrol stations, direct payments are an efficient and widely accepted payment method. However, depending on the specific direct payment solution, it may result in higher costs for charging equipment. Moreover, there is minimal interaction between the EV driver and the CPO regarding the acquired charging service.

The proposed AFIR regulation by the EC stipulates the requirement of payment terminals for fast charging stations (>50kW). However, the official text is not yet available at the time of writing. This development is expected to have an impact on the broader ECE region. Simultaneously, the Payment Services Directive (PSD II) ensures elements like Strong Customer Authentication (SCA), making it challenging to continue current payment practices and leading to significant additional installation costs. Consequently, discussions are currently underway to provide exemptions for direct payment at charging stations to ensure a seamless user experience with an acceptable risk profile (*ChargeUp Europe*, 2024).

Subscription model
Another well-established payment method is the subscription or post-payment model, commonly used for slow-charging infrastructure. In this model, the eMSP grants access to a charging station through authentication via a token, RFID card, app, or Plug&charge feature in the vehicle. Once authentication between the eMSP and the respective operator is successful, the charging session commences. After the session, the eMSP provides an invoice and facilitates settlement between the eMSP and CPO.
For EV drivers, the subscription model offers several advantages:

- The eMSP can provide a customized customer experience by offering additional services to enhance the charging experience, such as navigation, price transparency, rebates, and aggregated monthly invoice.
- Functionalities like smart charging, vehicle-to-grid (V2G), and Plug&charge can only be successfully developed within a subscription model because knowledge about the user, vehicle and its requirements is crucial. Important factors include departure time, required kilowatts, and state-of-charge.

Roaming

While a direct payment solution serves as a minimum standard for accessing multiple charging networks, it does not constitute true roaming for EVs since it relies solely on existing payment systems without providing further information or intelligence during the transaction.
The concept of roaming originates from the telecom sector, with ISO 26927 defining it as "a service that enables users/terminals to use access networks and mobility services of a network operator different from the user's home domain". In the context of electric mobility, EV roaming refers to allowing an EV user to have a subscription with operator/service provider *A* and charge the electric vehicle at a charging station operated by operator *B*, with whom the EV driver does not have a direct contract.

An open and interoperable market model

When combining the above insights into a future proof market model, the following picture arises.

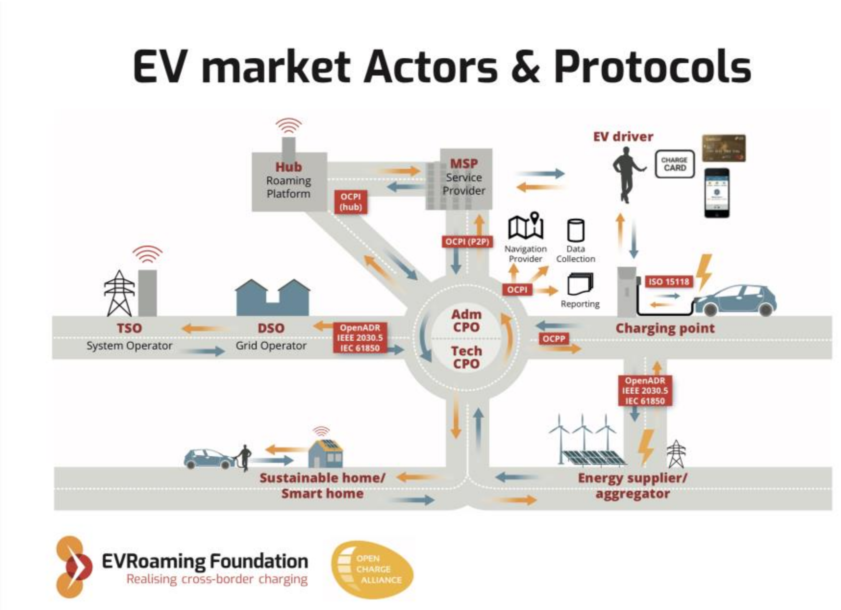


Figure 5 Ev Market and Protocols: EV market Actors & Protocols

*Source: (*EVRoaming Foundation*, 2023)*

This market model makes use of the requirements for openness and interoperability for the hardware, communication and information layers. Interoperability requirements for the services layer and the business layer (to assure uniform user-centric propositions, and a market model which provides the 'rules-of-the-game', respectively) will need to be described via regulation.

1.6. Charging Protocols in General

Open Charge Point Protocol (OCPP)/ IEC 63110

Operates between the charging station and the charging station management system: Open Charge Point Protocol (OCPP) has been developed to make it possible to connect different types/brands of charging stations to a single Charging Station Management System (CSMS) and vice versa, i.e. to connect a single type/brand of charging station to a range of charging station management systems. OCPP supports the management of charging stations and the handling of charging transactions, including the identification and authorization of the EV driver. In addition, the protocol can be used to control charging stations for smart charging. OCPP is used by the Charging Station Operator (CSO) to communicate with the charging stations it manages through its CSMS. OCPP has been developed into the international 'de facto' standard for managing charging stations and is used by many CPOs. OCPP is managed by the Open Charge Alliance.
IEC 63110 is the standardization effort by the IEC to develop a 'de jure' standard. Currently, the mandate has ended, and initiatives are ongoing to integrate the efforts of IEC63110 with OCPP.

Open ADR – Open Automated Demand Response Standard / OpenADR Alliance

The protocol's objective is to automate demand response communication, enabling systems and/or devices to adjust power consumption or production of demand-side resources. This adjustment can be triggered by various factors such as grid requirements, tariff adjustments, incentives, or emergency signals, all aimed at balancing demand with sustainable supply.

OSCP - Open Smart Charging Protocol/ Open Charge Alliance

The Open Smart Charging Protocol transmits forecasts of the electricity grid's available capacity to other systems. Operating on a budgetary model, the protocol enables client systems to convey their requirements to a central system. This central system ensures grid usage remains within limits by allocating budgets per cable. Should a system require additional capacity, it can request more, while systems needing less can return a surplus budget, making it accessible to other systems.

IEC 61850

The document IEC 61850-90-8 does not constitute a standalone protocol but rather serves as a technical report delineating an object model for electric mobility. It conceptualizes Electric Vehicles within the framework of Distributed Energy Resources as outlined in the paradigms established by IEC 61850.

Charging protocols – roaming

EV Roaming empowers EV drivers to charge at any charging station, regardless of the CPO or station owner, while overseeing the billing process for the charging session. Implementing EV roaming necessitates an open charging infrastructure tailored for electric drivers, which mandates adherence to specific standard protocols for its functionality.

OCPI - Open Charge Point Interface protocol/ IEC 63119

OCPI stands as an autonomous roaming protocol designed for seamless data exchange. Operates between the charging station operator and the mobility service provider: OCPI protocol is used to exchange information between the CSO and (MSP), but also with other market operators which require EV information. The OCPI protocol is used to set up a direct connection between two parties. It offers versatility, catering to both company-to-company interactions (peer-to-peer) and utilization through a roaming hub or platform, and supports the exchange of information on locations, tariffs, authorizations and charging transactions. It also supports smart charging through the management of charging profiles.
This protocol enjoys international support, providing EV drivers with visibility into charging point availability and costs. It is accessible at no charge through the EVRoaming Foundation, companies can become a contributor and thereby contribute to the development of the protocol.

IEC 63119 is the IEC standardization effort to develop a 'de jure' roaming protocol. Currently, efforts are ongoing to merge the initiatives of OCPI and IEC63119 in order to move to a single roaming protocol.

Proprietary Protocols

Proprietary protocols also exist, as developed by some roaming platforms for their own services, e.g. OCHP from e-clearing.net, OICP from Hubject and eMIP from Gireve. The general tendency is that all actors in the value chain move to a single protocol (OCPI) as the means of market communication.

ISO15118 / CHAdeMO

Operates Between the car and the charging station: ISO15118 was developed with two important goals: providing a user-friendly mechanism for authentication, authorization, and payment at the charging station without further user interaction, known as Plug and Charge (PnC) and for Integration of the EV into the Smart Grid to enable flexible energy transfer (V2G) and thereby deliver added value for the grid without compromising the EV or its driver.
Its latest extension, ISO15118-20, introduces significant enhancements such as support for wireless power transfer, improved data security with mandatory Transport Layer Security (TLS), and dynamic control modes for real-time power adjustments based on grid demands. It also includes multiplexed communication for efficient message processing and easier handling of multiple electric mobility contracts, allowing users to switch between different charging agreements effortlessly.

Having explored the broader EV charging ecosystem, we now turn our attention to the specific methods and strategies employed for charging electric vehicles. Understanding these approaches is crucial for evaluating the effectiveness and future development of charging infrastructure.

1.7. Types of Charging Infrastructure

The main current and upcoming charging methods competing today are:

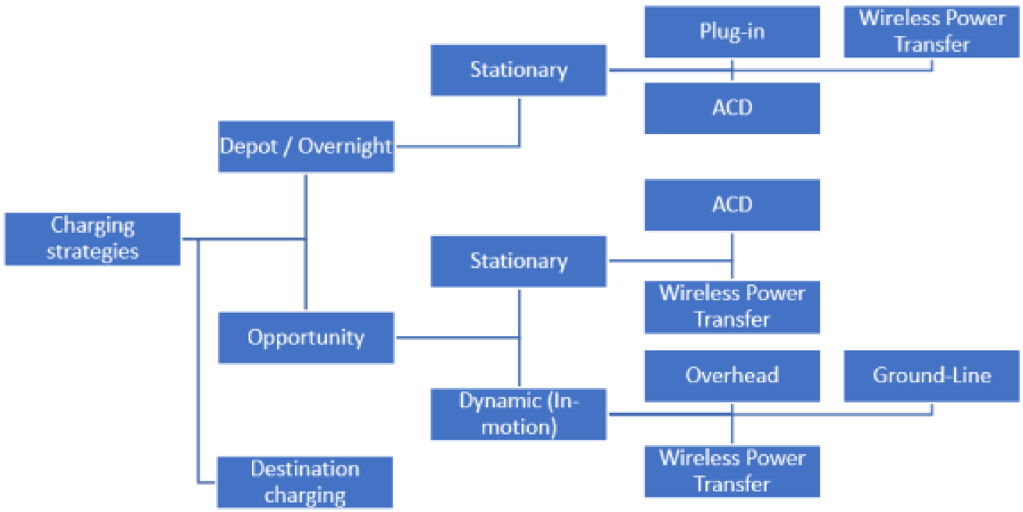


Figure 6 Types of Charging Infrastructure

Source: Standardisation and Harmonisation Specifications Related to Demo Actions

Depot / Overnight charging concepts

Static charging can be divided into two parts:

- *Conductive high-power connectors* (either man-operated with charging power values up to 300kW or automated for applications up to 1MW)
- *Wireless charging*, relying on wi-fi communication protocols.

Pantograph charging, or Type A charging, offers high-power charging (150-450 kW) primarily for depot use. While traditionally favored over plug-in chargers due to lower costs and simpler mechanics, there's a growing trend toward lower-power pantographs in depots. These systems are fully automated with advanced communication features, allowing flexible charging schedules to optimize bus operations.

Figure 7 Pantograph down ABB solution

Roof-mounted pantograph charging, or Type B charging, delivers higher power levels (150-600 kW) compared to Type A. This solution is well-suited for large bus fleets, enabling both overnight charging and rapid top-ups during the day. The Schiphol airport's 13 MW charging installation for 100 electric buses exemplifies this technology.

Figure 8 Pantograph up at IDIADA

Floor-mounted ACD is classified as Type C solution. In September 2019, Alstom presented in Malaga, Spain, the latest innovation of ground-based recharging systems – SRS dedicated to electric buses. It is equipped with a 200kW charger and is associated with a twelve-meter Linkker e-bus.

Figure 9 Floor mounted ACD Alstom solution

Dynamic charging or In-motion charging for overhead catenary trucks requires a long infrastructure to allow EVs to charge on-the-move, typically deployed on highways or intercity roads. It can be continuous or sectional, aerial or underground and inductive or conductive. Its main intended application is long-haul road transport.

Opportunity Charging

Opportunity charging means that the vehicle can charge during any opportunity available while the vehicle is stationary. This mainly includes charging with ACDs, wireless charging and flash charging.

One of the examples of opportunity charging with ACD is the implementation in Schiphol airport, Amsterdam.

Figure 10 450kW opportunity chargers at the Schiphol airport

Destination Charging

Several stakeholders present their Destination charging points as a global charging network solution for overnight charging at the end of a leg during a multi-day long trip. This can be at or near a hotel, AirBnb, or friend's/family's house.

Figure 11 Destination charging concept

According to *chargedfuture.com,* by utilizing destination charging, EV drivers can go significantly faster because the electric car is fully charged overnight. This is preferable to having to stop at another or two DCFC stations after leaving the hotel.

EV drivers mostly utilize the Plugshare website and app to locate a charging location. Plugshare is a tool for EV drivers to look for, rate, and navigate to charging stations.

The benefits of Destination Charging:

- The ease of charging the car while the driver is elsewhere occupied.

- By giving drivers a guaranteed charging station at their destination, 'range anxiety' can be eliminated.
- The assurance to avoid long lines at the service station for quick charging.
- The avoidance of a grid overload, given most destination charge sites use low-speed chargers.

1.7.1. LEV charging strategies

This section outlines innovative mobility options to be promoted in Solutions+ demos and specific cases for Light Electric Vehicles currently established in dedicated sites, focusing on the standardization, interoperability and charging infrastructure.

Bikeshare system

Some bike sharing systems are equipped to charge the bicycles when docked at stations, while others utilise battery swapping systems. Swapping systems may avoid the need for electrical connections at each station but can introduce the need for human labour to swap the batteries and for additional vehicles distributing the batteries.

Personal e-bikes

An external charger connected to a standard wall socket can charge a personal e-bike. The connection between the battery and its charger is not uniform among e-bikes; it varies by brand but is not a problem because the plug is standard (socket). Multiple versions enable battery swapping and removal. However, the charging technique remains the same.

Electric motorcycles taxis

The idea is to have dedicated charging stations for a taxi fleet that may be opened for public charging stations if there is enough power supply in this location. It is key for these shared vehicles to be used as much as possible and to have full certainty in the availability of dedicated charging whenever they need to be charged.

Personal LEVs

Motorcycles, scooters, and personal electric bicycles have relatively light electricity requirements and may be charged using standard wall outlets. Consumers are expected to be able to charge their devices at home or work using a standard wall outlet.

Insights On global Electric Vehicle Charging Infrastructure

2. INSIGHTS ON GLOBAL ELECTRIC VEHICLE CHARGING INFRASTRUCTURE

2.1 Insights from SOLUTIONSplus Cities

With an aim to reduce emissions from the transportation sector, the SOLUTIONSplus, project focused on revolutionizing sustainable urban transport through innovative and integrated electric mobility solutions. It brought together a global network of cities, industries, researchers, and implementing organizations. By working collaboratively, they implemented and tested electric mobility solutions via real-life demonstrations in various regions around the world, including Europe, Asia, Africa, and Latin America. The scope of the project can be majorly grouped into four themes: user needs assessment, light-duty passenger EVs, light-duty freight EVs, and MaaS applications.

This section will draw from the experiences of SOLUTIONSplus and provide an overview of charging solutions currently available in the SOLUTIONSplus cities.

A. Hamburg, Germany

Population	1.8 million. (*World Population Review*, 2023)
GDP per capita	$52,745.8 *(World Bank Open Data, 2024)*
CO2 Emissions	603,351 Kilo Tonne *(World Bank Open Data, 2024)*
Modal split	• 32% private vehicles, • 24% public transport, • 22% walking, • 22 % cycling. *(Mobility Turnaround in Hamburg, 2023)*
Solutions deployed	e-kick scooters
Charging Infrastructure deployment	Scooters with swappable batteries

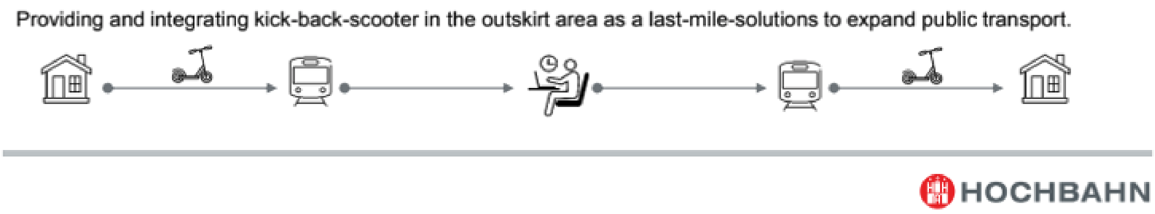


Figure 12 Hamburg: Demonstration action

Source: SOLUTIONSplus

B. Madrid, Spain:

Population	6.75 million. (*World Population Review*, 2023)
GDP per capita	$29,674 *(World Bank Open Data, 2024)*
CO2 Emissions	202,706 Kilo Tonne *(World Bank Open Data, 2024)*
Modal split	• 39% private vehicles, • 24% public transport, • 34% walking, • 3 % others, incl. cycling. *(SOLUTIONSplus)*
Solutions deployed	Charging Infrastructure for buses
Charging Infrastructure deployment	Two inverted pantographs were installed, offering modular charging power ranging from 90kW to 360kW.

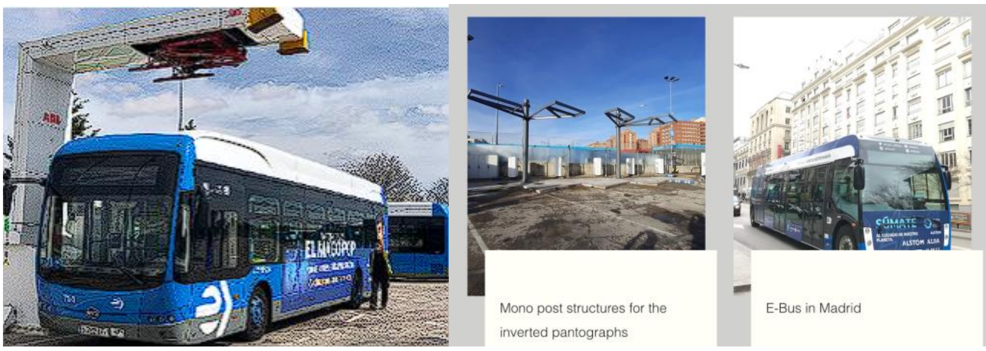


Figure 13 Madrid: Demonstration action

Source: SOLUTIONSplus

C. Quito, Ecuador

Population	1.95 million. (*World Population Review*, 2023)
GDP per capita	$6,166 *(World Bank Open Data, 2024)*
CO2 Emissions	34,431 Kilo Tonne *(World Bank Open Data, 2024)*
Modal split	• 9.3% private vehicles, • 52.2% public transport (buses),

	• 19.5% Taxis, • 15.3% walking, • 0.3% cycling. *(SOLUTIONSplus)*
Solutions deployed	• 10 e-cargo bikes • 4 e-mini vans (2 for cargo and 2 for passenger transport) • 4 e-quadricycles • MaaS implementation
Charging Infrastructure deployment	NA

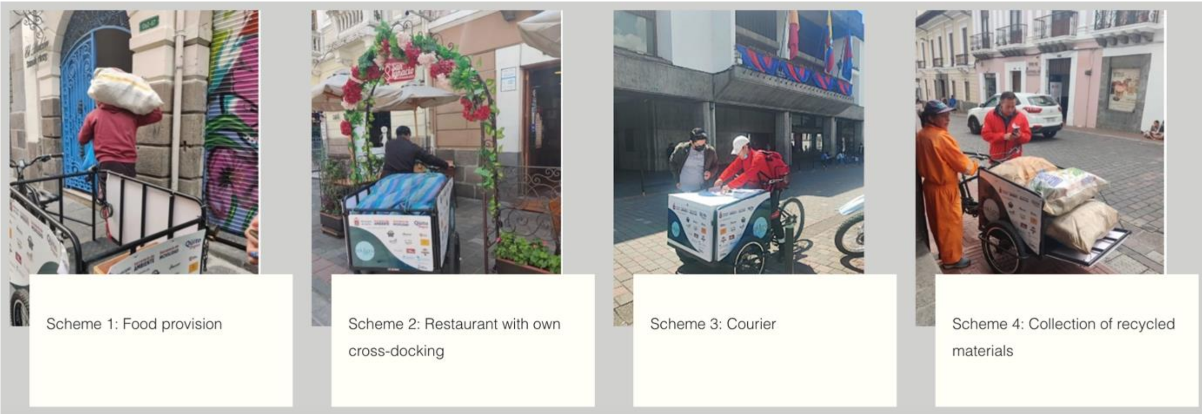


Figure 14 Quito: Demonstration action

Source: SOLUTIONSplus

D. Montevideo, Uruguay

Population	1.8 million. (*World Population Review*, 2023)
GDP per capita	$22,564.5 *(World Bank Open Data, 2024)*
CO2 Emissions	6,514 Kilo Tonne *(World Bank Open Data, 2024)*
Modal split	• 33% private cars or taxi, • 25% public transport (buses), • 34% walking, • 4% motorcycle, • 3% cycling, • 1% others *(SOLUTIONSplus)*
Solutions deployed	• e-buses (30 E-BRT Buses)

	• e-3 wheelers (3) • e-cargo bikes (8 e-cargo bikes [5 e-long-john + 3 e-three wheelers])
Charging Infrastructure deployment	The Municipality of Montevideo installed charging infrastructure for LEVs in Montevideo city centre, keeping interoperability between public and private service providers in mind.

Figure 15 Montevideo: Demonstration action

Source: SOLUTIONSplus

E. Pasig, Philippines

Population	0.8 million. (*World Population Review*, 2023)
GDP per capita	$3,725.6 *(World Bank Open Data, 2024)*
CO2 Emissions	133,471 Kilo Tonne *(World Bank Open Data, 2024)*
Urban passenger transport	• Public Utility Vehicles (PUVs, jeepneys and UV express or minivans), buses, tricycles (3-wheelers), and private modes. • Urban freight tasks involve heavy and light-duty trucks, delivery vans and motorcycles. • The most common means of travel within the city using public transport is by public utility jeepneys (PUJs) and UV Express minibuses for travel within and outside the city, as well as tricycles and city buses for in-city travel. Another common mode of transport in Pasig City is the tricycle, with a total of 13,169 tricycles registered with the local government. *(SOLUTIONSplus)*
Solutions deployed	Multi-purpose e-quadricycles

Charging Infrastructure deployment	Development of suitable charging solutions for e-quadricycles and other city government e-mobility vehicles.

Figure 16 Pasig: Demonstration action

Source: SOLUTIONSplus

F. Hanoi, Vietnam

Population	7.5 million. (*World Population Review*, 2023)
GDP per capita	$4,346.8 *(World Bank Open Data, 2024)*
CO2 Emissions	355,323 Kilo Tonne *(World Bank Open Data, 2024)*
Urban passenger transport	• 6% private cars, • 9% public transport (buses), • 73% motorcycle, • 2% Motorcycle taxi, • 4% cycling, • 6% Taxi *('Ngoc A.M. [et Al.]', 2022)*
Solutions deployed	• BetterGen charging • vehicle booking app • 50 shared e-mopeds
Charging Infrastructure deployment	NA

Figure 17 Hanoi: Demonstration action

Source: SOLUTIONSplus

G. Kathmandu, Nepal

Population	1.6 million. (*World Population Review*, 2023)
GDP per capita	$40,908.07 *(World Bank Open Data, 2024)*
CO2 Emissions	14,949 Kilo Tonne *(World Bank Open Data, 2024)*
Modal split	*(SOLUTIONSplus)*
Solutions deployed	• Converted diesel bus to e-bus (20-seater) • Remodelled Safa Tempo (11-seater) • Remodelled Safa Tempo cargo • e-3 wheelers (6-seater) passenger and e-3 wheeler cargo • e-3 shuttle van (6-seater) • Converted petrol mini truck to electric • e-waste collector
Charging Infrastructure deployment	NA

Figure 18 Kathmandu: Demonstration action

Source: SOLUTIONSplus

H. Kigali, Rwanda

Population	1.2 Million. (*World Population Review*, 2023)
GDP per capita	$2793 *(World Bank Open Data, 2024)*
CO2 Emissions	1,382 Kilo Tonne *(World Bank Open Data, 2024)*
Modal split	*(SOLUTIONSplus)*
Solutions deployed	• 80 conventional bicycles made available through the bike sharing system in the city • 50 electric bicycles made available through the bike share system • 4 electric buses deployed, offering an innovative financial model to bus operators • Electric motorcycles
Charging Infrastructure deployment	NA

Figure 19 Kigali: Demonstration action

Source: SOLUTIONSplus

I. Dar es Salaam, Tanzania

Population	7.7 million. (*World Population Review*, 2023)
GDP per capita	$1,211.1 *(World Bank Open Data, 2024)*
CO2 Emissions	14,436 Kilo Tonne *(World Bank Open Data, 2024)*
Modal split	• 3.7% private cars,

	• public transport,
	  ○ 47.9% - minibus users
	  ○ 3.3% BRT users
	  ○ 0.4% commuter rail
	  ○ 0.3% ferry
	• 39% walking,
	• 4.9% motorcycle,
	• 0.5% cycling,
	(range as indicated by DART, 2022 and JICA, 2018).

Solutions deployed	• 43 electric three-wheelers, deployed by four different companies. (39 new three-wheeled prototypes and three-wheelers locally assembled 4 retrofitted three-wheelers) • 16 pedal-assist electric bicycles • Charging infrastructure for e-3 wheelers
Charging Infrastructure deployment	The project replaced/ retrofitted a total of 43 ICE three-wheelers (bajajis) with electric models equipped with lithium-ion batteries. A detailed study of existing bajaji usage patterns determined the ideal battery capacity and charging strategy (SOLUTIONSplus Feasibility assessment to electrify feeder three-wheeled vehicles in Dar es Salaam, 2023).

Figure 20 Dar es Salaam: Demonstration action

Source: SOLUTIONSplus

J. Nanjing, China

Population	9.6 million. (*World Population Review*, 2023)
GDP per capita	$12,614.1 *(World Bank Open Data, 2024)*
CO2 Emissions	10,944,686 Kilo Tonne *(World Bank Open Data, 2024)*

Modal split	*(SOLUTIONSplus)*
Solutions deployed	LCMM localization 10 private cars, 1 bus from Nanjing and Beijing cities installed LCMM and underwent test drives on the base configuration and "ECO routing" configuration. The tests are compliant to SOL+ assessment requirements.
Charging Infrastructure deployment	NA

2.2 Overview of Protocols and Standards in SOLUTIONSplus

The following table presents an overview of the protocols/standards for EV charging infrastructure used in the SOLUTIONSplus project. The overview of these charging protocols will support establishing interoperability and standardization in emerging economies.

Table 3 Overview of Protocols/ Standards in SOLUTIONSplus Cities

Communication domain	**Overview - Use cases of current protocols/standards**	
EV-EVSE	IEC 61851-1	EV charging modes (current/intensity/tension/communication)
	ISO 15118	Communication between EV and CP, authorize charging session, reservation, smart charging (V2G - future version)
EVSE-CPO	OCPP	Authorize charging session, reservation, billing, CPO management, smart charging
Roaming	OCPI	Authorize charging session, reservation, billing, roaming, provision of CPO information
	OICP	Authorize charging session, reservation, billing, roaming, provision of CPO information
	eMIP	Authorize charging session, reservation, billing, roaming, provision of CPO information
	OCHP	Roaming, peer communication between market parties and EV clearing house
	OCHPdirect	Roaming, peer communication between market parties
Distributed energy resources	OSCP	Smart charging, grid management, capacity forecast
	OpenADR	Smart charging, demand response, price and load control
	IEC 61850-90-8	Object models for EVs, smart charging, integration with other DER types like PV, wind, etc.
	IEEE 2030.5	EV-home energy management system, demand response, exchange of metering data, usage and billing information

Building on our analysis of the SOLUTIONSplus project, we now turn our attention to the broader landscape of EV charging infrastructure. This section will examine national policies, regulations, and strategies implemented by global leaders and the largest markets in the field.

2.3National Policies, Regulation and Strategies

SOLUTIONSplus Countries- China

China is the leading country in the world, with more than 3.38 million EVs in 2019 (IEA, 2020) and sales of more than 1.2 million in 2020. Salient features of China's charging policy include:

- In 2015, the central government set a target of providing charging infrastructure for 5 million EVs by 2020, including 10% of parking spaces for EVs in large public buildings, at least one public charging station for every 2,000 EVs, and at least 120,000 EV charging stations.
- Provincial and local governments have established financial incentives and requirements for residential and commercial buildings to have EV charging.
- Five national standards were issued in 2015 for electric vehicle charging interfaces and communications protocols.
- The 13^{th} Five-Year Plan included RMB 90 million for charging infrastructure.

The central government sets policies on retail electricity rates, including minimum and maximum prices for electric vehicle charging. The National Development and Reform Commission (NDRC) policy included EV charging rates for three classes of customers. Residential customers pay residential rates (lowest tariff), dedicated central EV charging and battery swap stations pay industrial customer rate, and government offices, public parking lots, and other businesses pay commercial rates (highest tariff). Many Chinese provinces and cities have time-of-use rates for EV charging. The cap on EV charging tariffs was removed in Beijing in 2018 to make EV charging a viable business.

Montevideo, Uruguay

Uruguay's national push for e-mobility includes key initiatives supporting charging infrastructure development. The 2018 MOVÉS Project played a crucial role by establishing guidelines and promoting collaboration among stakeholders.

Regulations issued in 2022 set standards for publicly accessible charging stations. This ensures compatibility by mandating at least one Type 2 connector for alternating current and one CCS2 connector for direct current (*Decree No. 225/022*, 2022). These standardized connectors are essential for the seamless operation of electric vehicles, including public buses.

Furthermore, national programs like "Subite Buses" provide financial support for acquiring electric buses. While not directly related to charging infrastructure, this program incentivizes the deployment of electric buses, which in turn drives the need for more charging stations.

Dar es Salaam, Tanzania

Tanzania's national context for electrifying public transport presents a mixed picture. While policies promote sustainable transport modes like BRT systems and the national energy policy encourages renewable energy diversification, limitations exist. Current regulations do not offer incentives like tax exemptions for electric vehicles, hindering their wider adoption. However, stakeholders like DART (Dar es Salaam Rapid Transit Agency) are actively collaborating with UNEP (United Nations Environment Programme) to develop guidelines for clean energy technologies, including e-mobility, with support from the Ministry of Finance. These efforts suggest a potential shift towards a more supportive national framework for electrifying public transport in the future.

Pasig, Philippines

As part of the city's regulations, the local government has entered partnerships to develop the charging infrastructure within the city. This initiative aims to support the transition to EVs by providing adequate charging stations, thereby encouraging residents and businesses to adopt cleaner and more sustainable transportation options.

Pasig City is taking a leading role in promoting e-mobility, particularly for public transport. The National Department of Energy provided around 200 e-tricycles to the city. These e-tricycles are being used for various purposes: 20% are allocated to local government offices, with some designated for patient transport. The remaining 80% are distributed among public transport operators and for private use (SOLUTIONSplus Consortium, 2024).

Additionally, in 2016, Pasig City enacted an ordinance (Pasig City Ordinance 16, s2016 entitled Tricycle Upgrading Ordinance) aimed at phasing out two-stroke motorcycles for use in public tricycles. Under this ordinance, franchise owners were mandated to transition to either a four-stroke motorcycle or an electric three-wheeler, aligning with efforts to reduce emissions and promote environmentally friendly modes of transport.

Hanoi, Vietnam

In Vietnam, the regulatory framework on e-mobility is still in the early stages. The framework supporting EV deployment has not been fully developed. Nevertheless, the deployment of EVs, efforts to cut GHG emissions, and support from the local EV industry have recently brought the topic onto policy agendas. There are several government strategies and policies favouring EV deployment. However, these policies are general and mainly focus on promoting cleaner vehicles and developing fuel consumption standards for internal combustion vehicles. Therefore, there is a need to intensify the required effort in developing separate national regulations on e-mobility.

Currently, the development of transport policies and regulations in Vietnam is generally guided by four major national strategies, including:

(1) the National Climate Change Strategy (Decision No.2139/QD-TTg),

(2) the National Sustainable Development Strategy (Decision No. 432/QDTTg),

(3) the National Green Growth Strategy (Decision No. 1393/QD-TTg), and

(4) the Environmental Protection Law (Law No. 72/2020/QH14).

Based on these strategies, specific action plans and administrative decisions are executed.

Other Countries

Netherlands

In the Netherlands, the Dutch Ministry of Infrastructure and Water has drawn up a National Agenda Charging Infrastructure to ensure that a well-functioning infrastructure for electric transport can be rolled out. The National Agenda was drawn up in collaboration with public and private stakeholders, who jointly made agreements and defined the goals and actions on the deployment of charging infrastructure. The benefits of such a consultation have been reported, as it said to lead to improved coordination in the deployment of infrastructure, while ensuring broad multi-stakeholder buy-in.

India

India has an ambitious programme to transition to EVs. The Ministry of Power established the following measures (Potshangbam, 2019):

- Private charging at homes or offices will be permitted.
- There will be no licensing procedures to set up public charging stations.
- Stations should meet performance standards and protocols issued by the Ministry of Power and Central Electricity Authority.
- Minimum fast charger requirements specified for long-range and heavy-duty EVs. Charging stations for two and three-wheelers are given the flexibility to use any charger but need to meet specified technical and safety standards.
- Tariffs are determined by the electricity regulator. For domestic charging, the domestic tariff applies.

In addition, to promote faster adoption of electric vehicles, the Government of India has also allocated USD 135 million for subsidising charging stations. It is planning to set up at least one electric vehicle charging kiosk at around 69,000 petrol pumps (owned by public sector enterprises) across the country to induce people to go for electric mobility. It has also passed legislation allowing the sale of EVs without batteries to reduce their up-front costs and enable battery swapping.

Needs, challenges & opportunities

3. EVCI NEEDS, CHALLENGES AND OPPORTUNITIES

Building upon our analysis of the EV charging ecosystem, deployment trends and the charging infrastructure landscape in general, the upcoming section will dive deeper into the critical factors shaping charging needs and priorities.

While private charging at home and work remains the predominant means for charging EVs, public charging infrastructure plays an important role in fulfilling EV users' charging needs if driving for a longer time/distance or not having the possibility to charge at home or work. Notably, public charging infrastructure can reduce range anxiety and build confidence in the future EV market (Greene et al., 2020). For example, in the EU, a ratio of 10 EVs per charger is also recommended by the alternative fuel infrastructure regulations, and prior research indicates that to encourage e-vehicle uptake, the ratio of EVs per charging point should be between 5 and 25 (Harrison & Thiel, 2017) ('European Court of Auditors', 2021).

3.1 Challenges in Developing Charging Infrastructure

As discussed in section 1.3, the main actors involved in charging infrastructure and service provision are CPOs and MSPs (Anadón Martínez & Sumper, 2023). CPOs are responsible for installing and managing charging infrastructure, while MSPs focus on operations and customer interactions.

Three primary business models underpin public charging point operations: network-operator, owner-operator, and integrated models. The network-operator model involves charging providers for constructing and managing infrastructure, with site hosts handling fee structures and risks. In the owner-operator model, providers own and manage the entire charging network. Finally, the integrated model encompasses all aspects of charging operations, from equipment to pricing (Yong et al., 2023).

This variety of business models, however, also poses problems in ensuring interoperability between charging networks. Interoperability is the ability of electric vehicles to seamlessly interact with different chargers and process payments across multiple charging service providers. Currently one of the biggest difficulties faced by EV drivers is finding compatible charging stations, requiring multiple apps and payment methods.

To address these complexities, various solutions have been developed to enhance interoperability. One approach is charging roaming, allowing users to access different networks for a fee without additional subscriptions. This can be facilitated through peer-to-peer agreements or centralized hubs, utilizing protocols like Open Charge Point Interface Protocol (OCPI) or Open Inter Change Protocol (OICP). Additionally, umbrella payment platforms can simplify the payment process across multiple networks.

Furthermore, the figure below illustrates insights into the barriers to e-mobility implementation from a survey conducted under the SOLUTIONSplus project. A vast majority of respondents (66% and 65%, respectively) see investments in infrastructure and the lack of financial resources as the most significant challenges for e-mobility implementation in their respective cities. From a regional perspective, infrastructure and financial resources remain in the top 3 challenge lists for all continents.

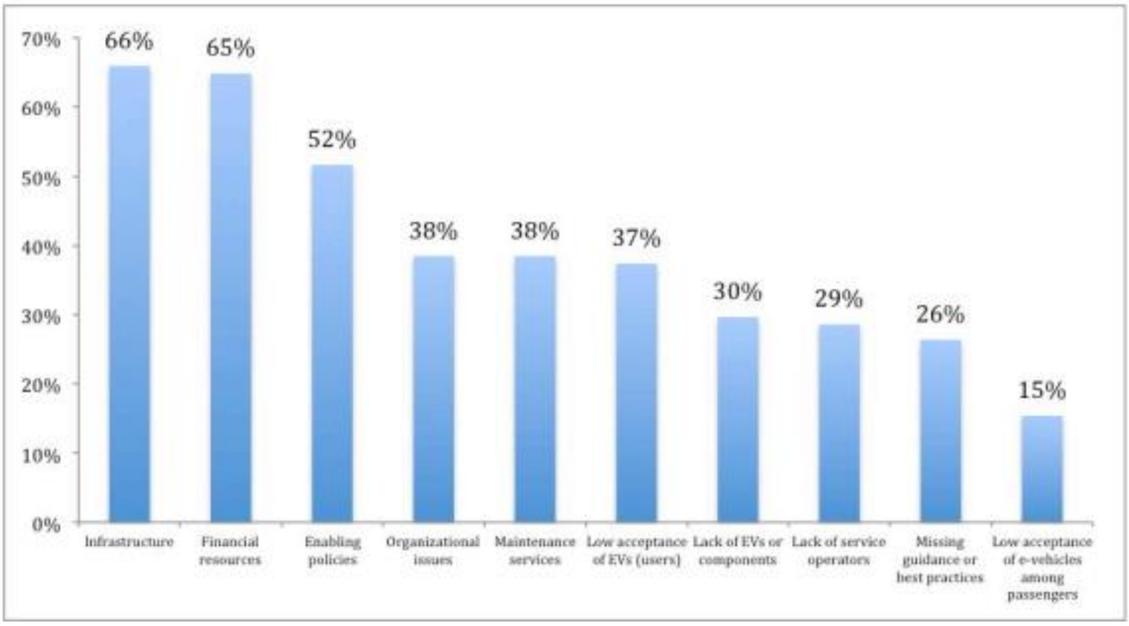


Figure 21 Main Challenges identified across SOLUTIONSplus cities

Issues of interest that surfaced through interviews include:

- regulatory and governance aspects that hinder e-mobility proliferation (in 3 out of 9 cities),
- the lack of technical standards (4/9), and
- the lack of clear/sufficient homologation and registration regulations for EVs (4/9).

The capacity of the electricity grid to meet the electrification challenge, lack of technical skills, concerns regarding urban planning and space requirements for the implementation of e-mobility solutions, as well as diverging objectives of different stakeholder groups were also referred to as problems to be addressed.

3.2 Charging Needs and Priorities

Charging needs and priorities refer to the specific requirements and preferences of EV users and the broader energy system when it comes to charging infrastructure. These factors influence the planning, design, and operation of charging networks.

Charging needs are influenced by the following factors:

I. **User needs:** These encompass factors like charging speed, location, accessibility, cost, and convenience. For example, a commuter might prioritize fast charging stations near highways, while a residential user might prefer home charging.

II. **Vehicle characteristics:** Different EV models have varying battery capacities and charging rates, impacting charging times and infrastructure requirements.

III. **Geographic location:** Urban, suburban, and rural areas have distinct charging needs, with urban areas generally requiring higher charging densities.

Whereas the Charging Priorities are influenced by:

- **Grid stability:** Ensuring that EV charging doesn't overload the electricity grid is a critical priority. This often involves smart charging technologies and load management.
- **Environmental impact:** Prioritizing renewable energy sources for charging and minimizing energy consumption is essential for reducing the environmental footprint of EVs.
- **Economic viability:** Charging infrastructure should be financially sustainable for both operators and users. This includes factors like pricing, revenue models, and investment returns.
- **Equity:** Ensuring that charging infrastructure is accessible to all users, regardless of socioeconomic status or location, is crucial for equitable EV adoption.

By understanding these charging needs and priorities, policymakers, infrastructure providers, and EV manufacturers can develop effective strategies for deploying and managing charging networks.

Key Aspects of Charging Needs and Priorities

1. **Charging safety**

The risk of accidents related to the charging of EVs is expected to grow with the proliferation of e-mobility. The lack of institutionalized standards in the country can aggravate this risk. The formal standardization of locally produced EVs is expected to reduce this risk in addition to facilitating consumer trust. Electrical shock exhibits the highest risk for converted and remodelled vehicles, as these vehicles may be more prone to equipment malfunctions or human errors during maintenance/repairs. The new designs are expected to suffer more by instability in the power grid, which, despite minor/low impact, occurs frequently in Nepal due to intermittent power supply and voltage fluctuations.

Therefore, ensuring charging safety is a key element in the pursuit of e-mobility solutions. Consideration towards the type of batteries and their charging technology/infrastructure to be utilized must be noted when assessing risks associated with battery operation and charging (i.e. conductive, inductive, battery swapping), as well as whether communication and charging coordination are featured in the system. Below is a list of primary risks associated with the charging infrastructure.

1.1. Electrical shock to users and personnel:

Charging facilities can cause electrical hazards, which can include potential electrical shock to customers (if applicable to the design of the project), as well as electrical shock and arc flash hazards to workers. Examples of instances which can lead to electrical shock include potential failure of ground fault circuit-interrupting breaker and potential failure of charging circuit-interrupting devices due to environmental factors or due to vandalism activities like copper theft (Wang et al., 2019).Electric shock hazards greatly depend on the characteristics of the charger. Protection against electric shock can be achieved through basic protection (e.g. preventing persons from being in contact with the energized components or parts), and fault protection (protection in the event of failure of the basic insulation via disconnection of the supply). The reliability of the charging components with electrical safety protection features should be monitored and assessed through periodic safety inspections.

1.2. Fire hazards:

Fire hazards caused by the charging of EVs may also affect personnel safety, as well as result in damage to property. Lithium-based batteries, for example, can self-ignite due to manufacturing errors, short-circuiting, exposure to extreme heat, or damage to the battery cell (*Electric Vehicle Battery Fire Risks - Terrell • Hogan*, 2020). The pursuit of fast charging (and discharging) combined with the high driving performance of EVs is also documented to have a negative effect on fire risk (Sun et al., 2020). Fires due to charging may result from instances related to the following: overcharging, short-circuiting, overheating of the charging environment, ignition of flammable materials, cable overload, faulty or insecure charging stations and cables, improper installation, improper charging practices, failure of the onboard charging equipment, and failure of the charging system in general. Protection against external forces that may result in fires should also be taken into consideration (e.g. arson, burning in the vicinity, among others).

1.3. Power grid instability:
The potential impacts of the high penetration of uncontrolled charging can result in negative impacts to the power system due to potentially significant increases in peak demand; voltage deviation from acceptable limits; phase unbalance due to single-phase chargers; harmonics distortion; overloading of power system equipment; increase of power losses (Habib et al., 2014). The main key variables are: penetration level (i.e. the amount of EVs to be introduced into the system); the EV battery charger (i.e. fast chargers expected to increase peak demand than slow chargers); time of charging (i.e. EVs charging at the same time; interference with the peak demand time); location; battery capacity (i.e. high capacity batteries will draw larger amounts of energy); battery state-of-charge; state of the distribution system (e.g. structure, equipment loading conditions, voltage level, and profile, load profile, etc.) (Nour et al., 2022).

3.3 Opportunities

As mentioned in the previous section One of the main barriers to EV adoption is the scarcity of adequate and accessible charging infrastructure, which causes range anxiety and inconvenience for potential EV users. Therefore, it is important that public charging stations are deployed in strategic locations that can meet the needs of users and encourage more people to switch to EVs.

The guidelines that can orientate the selection of charging station sites in a cost-effective way, with the goals of encouraging the transition from ICEVs to EVs and accelerating the decarbonization of transport are presented below-

1. **Employ a data-driven approach for planning EV charging station siting.**

To be efficiently located, charging stations need to be planned with a data-driven approach. Statistics on electricity demand, vehicle fleet characteristics, and the supply of semi-public and private charging facilities can be used to identify points of charging demand in a study region. Real-world travel data can help understand where EV drivers spend significant time, indicating suitable places for deploying charging stations.

2. **Plan for charging infrastructure deployment over time.**

A multi-periodic approach can account for the predicted evolution of the EV market, as well as the changes in mobility patterns, electricity demand, and grid capacity over time. This can help avoid over-investing in infrastructure that may become under-utilised or obsolete or under-investing in infrastructure that may cause bottlenecks or reliability issues. Genetic algorithms can be employed to model optimal locations in different time horizons, allowing for plans to be adjusted accordingly.

3. **Consider the interaction between transportation and power distribution networks.**

To mitigate the adverse effects of EV charging on the power grid, not only data on mobility patterns should be considered for choosing ideal charging station locations, but also on the local electricity demand and the hosting capacity of the electricity network. By optimising infrastructure use, potential risks to the stability and dependability of the electricity system can be mitigated.

4. **For most cases, regular charging infrastructure should be preferred over fast charging**

infrastructure.

In contrast to fast charging equipment, regular charging equipment exerts less pressure on the electricity network, provides greater efficiency, and slows EV battery degradation. Strategically placing regular charging equipment could enhance charging infrastructure coverage while minimising both the investment costs and the burden on the power grid. Fast charging equipment deployment should be orientated by the need to meet certain performance criteria, such as offering quick partial recharging for taxis and city buses (Fadel da Costa, 2024).

4. CONCLUSION

This report presented provides a comprehensive analysis of the dynamic e-mobility landscape, specifically regarding charging infrastructure, from a global perspective. The European Union stands out as a benchmark in the field of e-mobility through its proactive regulation, strategic planning, and stringent interoperability standards. Its approach to harmonizing market models and fostering a user-centric environment offers valuable insights that can guide other regions in their e-mobility journeys. Therefore, this report analyses the needs, challenges and opportunities for EV Charging from an international context by studying the case of SOLUTIONSplus cities.

As described in the previous sections, different regions have developed unique market models influenced by historical, local, and policy contexts. In the first section, the report emphasizes the importance of maintaining an open and competitive market for the successful scale-up and operation of EV charging networks. Hence, ensuring seamless connectivity and standardized protocols is vital for the widespread adoption of electric vehicles, as interoperability enhances user experience, promotes competition, and facilitates efficient back-end processes.

Effective deployment strategies should prioritize accessibility, reliability, and user satisfaction. Hence, it is very important to acknowledge the needs, priorities and challenges associated with EVCI and further list the opportunities linked to the EVCI in various regions of the world.

Additionally, it should also be acknowledged the EVCI technology and standards developed by the EU are influenced by the predominant needs, challenges and shortcomings in the EU region. For delivering charging solutions to non-EU regions, it is necessary to adapt to the unique and diverse transportation needs of non-EU regions, where lighter vehicles (motorcycles, three-wheelers) are more common. This includes analysing potential adjustments to battery standards, software hardware and policy considerations.

Overall, the insights from this report offer actionable recommendations for policymakers, industry stakeholders, and governments to foster the development of robust and sustainable EV charging infrastructure. By leveraging global best practices and adapting them to local contexts, regions can accelerate their transition to e-mobility, contributing to a greener and more sustainable future.

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