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**Economic Commission for Europe****Inland Transport Committee****Working Party on Transport Trends and Economics****Thirty-sixth session**

Geneva, 4–6 September 2023

Item 8 (a) of the provisional agenda

**Review and monitoring of emerging issues and sustainable development goals:****Transport Trends and Challenges in the road, rail, and inland waterways sectors****General trends and developments surrounding electric vehicles and their charging infrastructure – deploying a sufficient charging network\*****Note by the secretariat****I. Introduction**

1. Further to the request of the Working Party on Transport Trends and Economics (WP.5) at its previous session to designate its Transport Trends and Economics 2022–2023 publication on general trends and developments surrounding electric vehicles and their charging infrastructure, a draft publication as contained in ECE/TRANS/2023/4, ECE/TRANS/2023/5, ECE/TRANS/WP.5/2023/6, ECE/TRANS/WP.5/2023/7, and ECE/TRANS/WP.5/2023/8 has been elaborated by the secretariat and an external consultant and will be presented for feedback.
2. The present document provides a comprehensive overview of latest trends in deployment of sufficient charging networks. It covers a broad range of definitions and distinguishes among public, publicly accessible, and private charging opportunities. It further elaborates on various charging infrastructure policies and defines different contracting and market models. It then explores opportunities for harmonization across these models and the creation of a more open and interoperable market.
3. WP.5 delegates are invited to provide feedback and suggestions for improvement of the text and to deliver presentations on national case studies and best practice examples for inclusion in the final version of the publication.

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\* This document was scheduled for publication after the standard publication date owing to circumstances beyond the submitter's control.



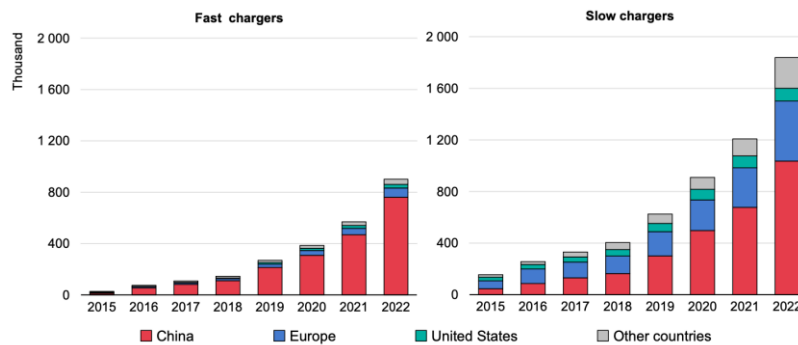
## II. Charging infrastructure

### A. Charging infrastructure at a global level

4. In 2022, more than 600,000 public slow charging points ( $\leq 22\text{kW}$ ) were installed globally. Of these, 360,000 were in China, bringing the country’s total slow charger stock to over 1 million (IEA, 2023). Europe ranked second, with a total of 460,000 slow chargers in 2022, representing a 50 per cent increase from the previous year. Among European countries, the Netherlands led with 117,000 slow chargers, followed by approximately 74,000 in France and 64,000 in Germany. In the United States, the stock of slow chargers increased by 9 per cent in 2022, which was the lowest growth rate compared to other major markets. In Korea, the number of slow charging points doubled year-on-year, reaching 184,000.

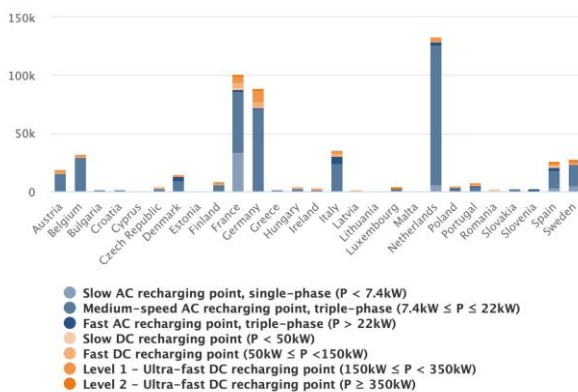
5. Regarding fast chargers ( $22\text{kW} < P < 350\text{kW}$ ), there was a global increase of 330,000 in 2022. However, most of this growth (almost 90 per cent) occurred in China. In Europe, the overall stock of fast chargers exceeded 70,000 by the end of 2022, representing a 55 per cent increase compared to 2021. Germany had the largest number of fast chargers with over 12,000, followed by France with 9,700, and Norway with 9,000. In the United States, 6,300 fast chargers were installed in 2022, of which approximately three-quarters were Tesla Superchargers. The total stock of fast chargers reached 28,000 by the end of 2022.

Figure I  
The number of installed publicly accessible light duty vehicle charging points by power rating and region



Source: IEA (2023)

Figure II  
Total number of alternating current (AC) and direct current (DC) recharging points in 2022



Source: European Alternative Fuels Observatory.<sup>1</sup> Accessed on 30 May 2023.

<sup>1</sup> <https://alternative-fuels-observatory.ec.europa.eu/transport-mode/road/european-union-eu27/country-comparison>

## B. Sufficient charging network

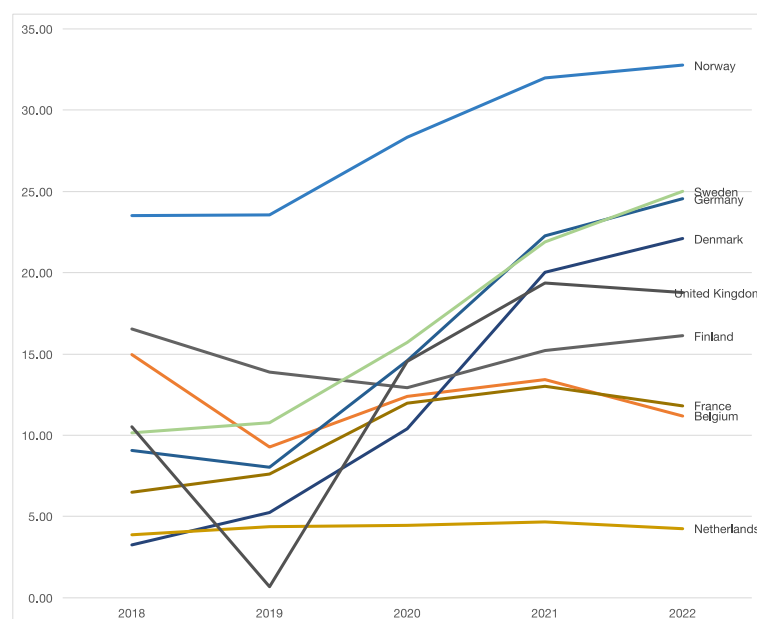
6. When considering the electrification of transport, adequate charging infrastructure is an essential component of the ecosystem. When considering planned electrification ambitions, it is important to determine what constitutes a ‘sufficient’ charging infrastructure. This can vary significantly from country to country. It depends on factors such as the number of vehicles to be accommodated, the distribution of alternating current (AC) and direct current (DC) charging stations, and various other considerations. Even within a country, the required amount of charging stations will differ per region when considering localized differences across regions, including fleet configuration (BEV vs PHEV, average battery size etc.), housing stock, level of urbanization, population density, and average usage of a BE (e.g. distance travelled).

7. To establish a definition for ‘sufficient’ charging infrastructure and ensure proper deployment, Key Performance Indicators (KPIs) have been developed in recent years to capture this. Some of the KPIs that have been defined in the past, as part of the European Alternative Fuels Infrastructure Directive (2014/94/EU)<sup>2</sup> or through national guidelines (IEA, 2022) include the following:

- Number of EVs per public charging point = 10 (excluding non-public initiatives)
- Number of EVs per publicly accessible charging point = 4 (excluding private charging networks)
- Number of EVs per charging point (public and private) = 1 (excluding considerations of slow/fast charger capacity)

Figure III

### Electric cars per public charging point in select Economic Commission for Europe member States



Source: IEA Global EV Data Explorer.<sup>3</sup> Accessed on 31 May 2023.

8. To address the different charging requirements of BEVs and a PHEVs, as well as account for the various charging capacities of slow and fast chargers, specific targets have been outlined in the newly proposed European Commission Regulation for the deployment of alternative fuels infrastructure (AFIR).

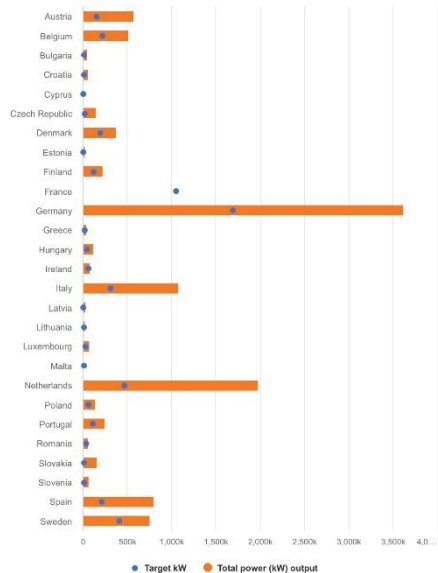
<sup>2</sup> [https://transport.ec.europa.eu/system/files/2021-06/sustainable\\_transport\\_forum\\_report\\_-\\_recommendations\\_for\\_public\\_authorities\\_on\\_recharging\\_infrastructure.pdf](https://transport.ec.europa.eu/system/files/2021-06/sustainable_transport_forum_report_-_recommendations_for_public_authorities_on_recharging_infrastructure.pdf), section 2.3.1.1

<sup>3</sup> <https://www.iea.org/data-and-statistics/data-tools/global-ev-data-explorer>

These targets are as follows:

- For every battery electric LDV registered within a country’s territory, publicly accessible recharging stations must provide a minimum total power output of 1 kW.
- For every plug-in hybrid LDV registered within a country’s territory, publicly accessible recharging stations must provide a minimum total power output of 0.66 kW.

Figure IV  
Total power output per AFIR fleet-based target



Source: EAFO ‘target tracker’ <https://alternative-fuels-observatory.ec.europa.eu/transport-mode/road/european-union-eu27/target-tracker>

9. When establishing specific target values for the aforementioned KPI’s, it is essential to consider localized differences across regions as explained in paragraph 6 above. Furthermore, even if sufficient kW per EV is available, ensuring EV driver access to charging is an important consideration, as a charging network with limited interoperability can pose challenges.

10. The aforementioned considerations necessitate a customized approach to adequately support the growth of EVs.

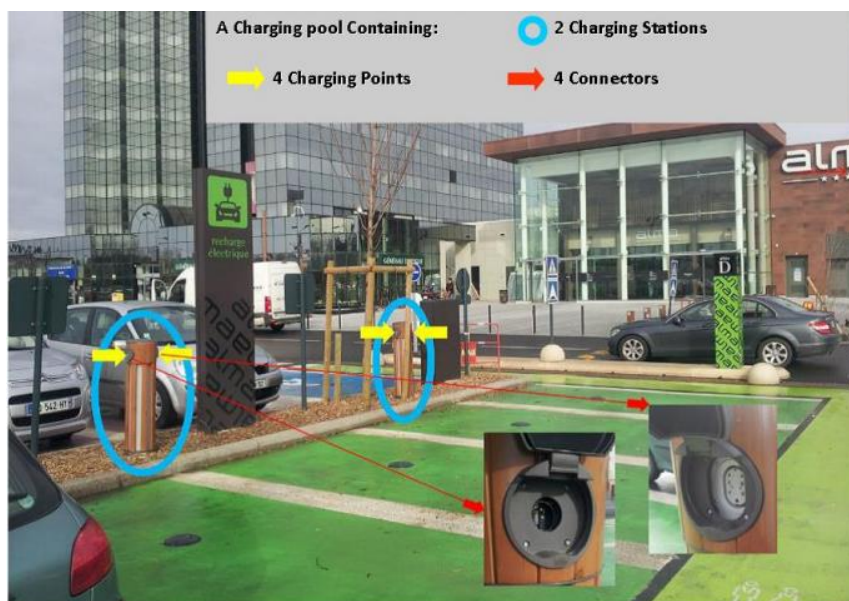
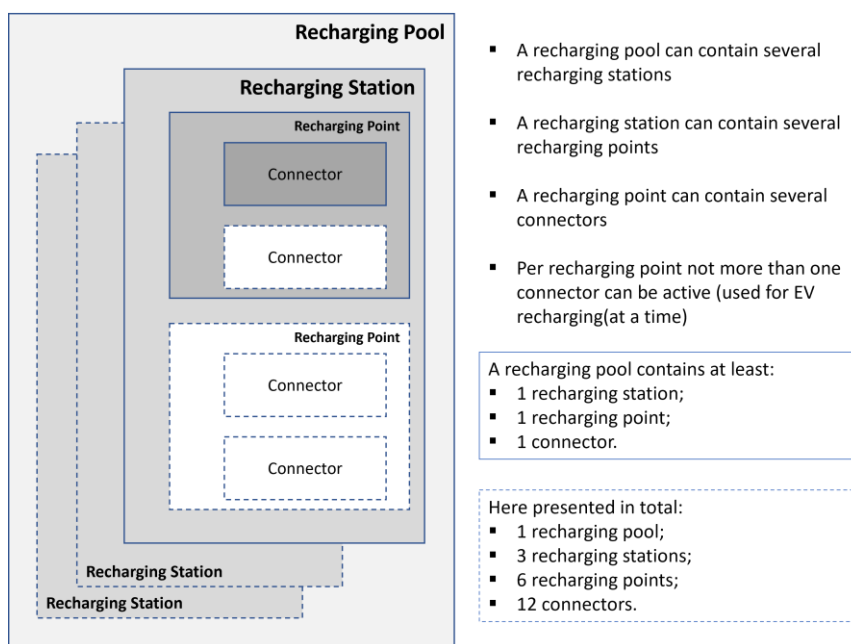
### C. Definitions and standards

11. This section provides an overview of the terms and definitions related to charging stations, and the (hardware) standards adopted. Multiple extensive descriptions also exist online that can be further consulted.<sup>4</sup>

12. Numerous terms are used to describe charging infrastructure which may differ per continent and authority. The European Alternative Fuels Observatory of the European Commission provides a reliable benchmark for understanding these elements. The figure below illustrates the various terms. The term “recharging” is specific to the European Commission, while “charging” is more commonly used globally. In this study, we use the more general term “charging”.

<sup>4</sup> European Alternative Fuels Observatory (<https://alternative-fuels-observatory.ec.europa.eu/general-information/recharging-systems>); Netherlands Enterprise Agency ([https://www.rvo.nl/sites/default/files/2019/01/Electric%20Vehicle%20Charging%20-%20Definitions%20and%20Explanation%20-%20january%202019\\_0.pdf](https://www.rvo.nl/sites/default/files/2019/01/Electric%20Vehicle%20Charging%20-%20Definitions%20and%20Explanation%20-%20january%202019_0.pdf)); IEA (<https://www.iea.org/reports/global-ev-outlook-2022/trends-in-charging-infrastructure>)

Figure V  
Recharging pool, -station, -point, -connector



Source: European Alternative Fuels Observatory. Available at <https://alternative-fuels-observatory.ec.europa.eu/general-information/recharging-systems>. Accessed on 30 May 2023.

## 1. Alternating current and direct current charging

13. AC stands for ‘alternating current’, which is the type of current that flows through high- and low-voltage grids. An AC charging station directly provides AC to the EV and is typically a low capacity ( $\leq 22\text{kW}$ ) charging station with small dimensions. As the EV uses DC current, the on-board charger in the car converts AC to DC.

14. DC refers to ‘direct current’, which is the type of current used by batteries. Any DC charging station converts AC from the grid to DC, resulting in a larger charger size and often requiring cooling facilities. DC chargers can provide higher capacities (up to 1MW and beyond) directly to the EV.

15. Different modes of charging are recognized to accommodate the various types of current, voltage, and phases available.

16. In addition to defining AC versus DC charging points, it makes sense to distinguish between charging capacities. Specific categories can be coupled to specific use cases for charging (see later in this chapter).

Table 1  
**Categories of charging points**

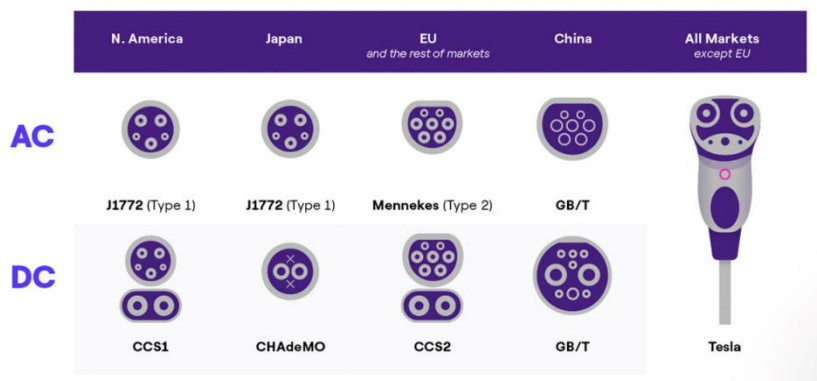
Category	Sub-category	Maximum power output
Category 1 (AC)	Slow AC recharging point, single-phase	$P < 7.4 \text{ kW}$
	Medium-speed AC recharging point, triple-phase	$7.4 \text{ kW} \leq P \leq 22 \text{ kW}$
	Fast AC recharging point, triple-phase	$P > 22 \text{ kW}$
Category 2 (DC)	Slow DC recharging point	$P < 50 \text{ kW}$
	Fast DC recharging point	$50 \text{ kW} \leq P < 150 \text{ kW}$
	Level 1 - Ultra-fast DC recharging point	$150 \text{ kW} \leq P < 350 \text{ kW}$
	Level 2 - Ultra-fast DC recharging point	$P \geq 350 \text{ kW}$

Source: EAFO.<sup>5</sup> Accessed on 7 June 2023.

## 2. Charging connectors

17. Worldwide, different charging connectors have emerged in the last decade as regional standards, as visualized below. 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 VI  
**Charging connectors**



Source: EnelX. Accessed on 7 June 2023.<sup>6</sup>

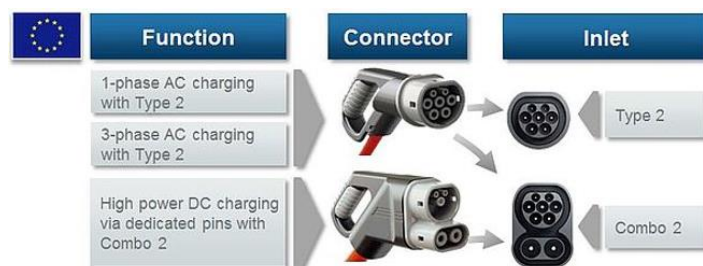
18. In the European Union, the Type 2 connector has been prescribed for AC charging and the Combined Charging System (CCS) 2 has been prescribed as the DC connector standard for DC charging. “Alternating current (AC) high power recharging points for electric vehicles shall be equipped, for interoperability purposes, at least with connectors of Type 2 as described in standard EN 62196-2. Direct current (DC) high power recharging points for electric vehicles shall be equipped, for interoperability purposes, at least with

<sup>5</sup> <https://alternative-fuels-observatory.ec.europa.eu/general-information/recharging-systems>

<sup>6</sup> <https://www.enelxway.com/us/en/resources/blog/ev-charging-connector-types>

connectors of the combined charging system ‘Combo 2’ as described in standard EN 62196-3.”<sup>7</sup>

Figure VII  
Type 2 and CCS/Combo 2



Source: EAFO.<sup>8</sup> Accessed on 7 June 2023.

19. In the United States, some carmakers (Ford, GM<sup>9</sup>) have recently chosen to adopt the Tesla DC standard (North American Charging Standard or NACS<sup>10</sup>) for their vehicles instead of CCS1, in order to gain access to the widely deployed Tesla Supercharger network and the corresponding NACS standard. Apparently, even on hardware interoperability, consolidation is still taking place. While interoperability can be maintained with hardware adapters or providing charging stations with multiple connectors, cost implications and user-friendliness are aspects that need to be addressed in this context.

### 3. Megawatt charging

20. In addition to the above, a new Megawatt Charging Standard (MCS) is in development for heavy-duty vehicles. This initiative is under the coordination of Charin and provides heavy-duty trucks with a charging capacity potentially of almost 4MW. (Voltage will range between 500-1250V, and the current has been tested up until 3000A). It is therefore a very important step towards the future of heavy-duty charging and other high-capacity modalities such as e-aviation. The MCS concept as described by Charin ranges beyond a charging system and connector, but includes recommendations on e.g. location aspects (‘drive-through charging’) software standards (OCPP, ISO15118) etc.<sup>11</sup>

21. The European Union and the United States have cooperated to develop a shared vision on a standard for charging electric heavy-duty vehicles. This achievement is also accompanied by recommendations resulting from the long history of scientific collaboration between the European Union Joint Research Centre and the United States Department of Energy's Argonne National Laboratory. We recognize the Megawatt Charging System (MCS) adoption by IEC, SAE and ISO for the charging of electric heavy-duty vehicles, where the alignment of our approaches to standardization will be critical for the roll-out of dedicated recharging infrastructure. Both sides applaud efforts towards compatibility of physical connectors (plugs) and a common vehicle-to-grid communication interface for all power levels, recognizing that additional solutions may be possible among private sector operators.<sup>12</sup>

## D. Deployment of charging infrastructure- publicly accessible and private charging

22. When defining the charging function or purpose, a distinction is often made between public and private charging. Public charging refers to providing non-discriminatory access to charging, often with an associated business model. Private charging, on the other hand,

<sup>7</sup> <https://eur-lex.europa.eu/legal-content/EN/TXT/HTML/?uri=CELEX:32014L0094#d1e32-19-1>

<sup>8</sup> <https://alternative-fuels-observatory.ec.europa.eu/general-information/recharging-systems>

<sup>9</sup> <https://news.gm.com/newsroom.detail.html/Pages/news/us/en/2023/jun/0608-gm.html>

<sup>10</sup> <https://www.tesla.com/blog/opening-north-american-charging-standard>

<sup>11</sup> <https://www.charin.global/technology/mcs/>

<sup>12</sup> [https://ec.europa.eu/commission/presscorner/detail/en/statement\\_23\\_2992](https://ec.europa.eu/commission/presscorner/detail/en/statement_23_2992)

involves charging for personal use, use within fleets, or for known (guest) users. It is important to consider the legal context, as a charging station can be located on either public or private territory, regardless of its public or private charging function. Based on these definitions, the following distinctions are made:

- **Public charging:** Charging for public use in the public domain. The deployment of public charging is largely affected by policy choices of local and regional governments. Being deployed in the public domain, strict rules and procedures need to be adhered to in planning and deployment. Access is considered to be unrestricted: every EV driver is able to charge at any period of time, without any access restriction.
- **Semi-public charging:** Charging for public use on private territory. This is a broad category that includes privately owned and operated charging stations that are accessible to the public. Restrictions may be present, either through access restrictions (in a parking garage behind a gate), time restrictions (“open from 8.00AM-8.00PM”), or restrictions in user groups (e.g. charging tariff differentiation for customers versus non-customers). This category is called ‘semi-public’ because the purpose is to provide, within constraints, a charging service for a broader audience of (unknown) EV drivers.
- **Private charging:** Charging for private use on private territory. This includes home charging, charging for own fleets, and for employees at the workplace. It may also include guest usage for (known) customers and may even require authentication, or some form of charging cost. But the key differentiator is that there is no intention to provide a charging service to a broader audience. And in contrast to the above categories, these charging stations will not be displayed on any map or navigation service.
- The European Commission has defined the categories public charging and semi-public charging as publicly accessible charging.<sup>13</sup> In addition, the terms ‘unrestricted’ and ‘restricted’ charging have been coined to differentiate between the two.

23. These definitions are significant because the usage statistics often rely on publicly accessible charging infrastructure, while private charging for passenger vehicles, for example, can account for up to 75 per cent of the total charging network, see the table below as an illustration. Consequently, private charging has a substantial impact on (public) charging network strategies. Also, public government may want to develop policies that explicitly distinguish between public and semi-public charging station deployment, as the approach, tools and incentives are very different, but they jointly make up the total publicly accessible charging network.

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<sup>13</sup> <https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=celex%3A32014L0094>



Table 2  
**Number of charging points in the Netherlands, distinguishing between public, publicly accessible and private charging points**

<i>Number of charging points at the end of</i>	2018	2019	2020	2021	2022	April 2023
Regular public + semi - public	35 861	49 520	63 586	82 876	119 197	128 581
• Regular public (24/7 publicly accessible)	20 228	27 773	39 968	51 423	69 804	75 437
• Regular semi-public (limited publicly accessible)	15 633	21 747	23 618	31 453	49 393	53 133
Fast charging points, public + semi – public	1 116	1 262	2 027	2 577	4 164	5 207
• off which > 100kW		433	897	1 307	1 878	2 708
Fast charging locations	197	339	467	629	972	1 066
All regular + fast charging points	36 977	50 772	65 613	85 453	123 361	133 788
Number of plug-in passenger car (BEV+PHEV) per charging point	3.7	3.9	4.2	4.5	4.2	4.3
Private charging points <sup>1</sup>	-80 000	-114 000	-158 000	-221 000	-345 000	-384 000

*Source: Netherlands Enterprise Agency (2023)*

## E. Deployment strategies

24. A typical long-term strategy for passenger vehicle charging infrastructure for any region involves several steps that often overlap and depend on the local context. These steps are reiterated as the sector matures:

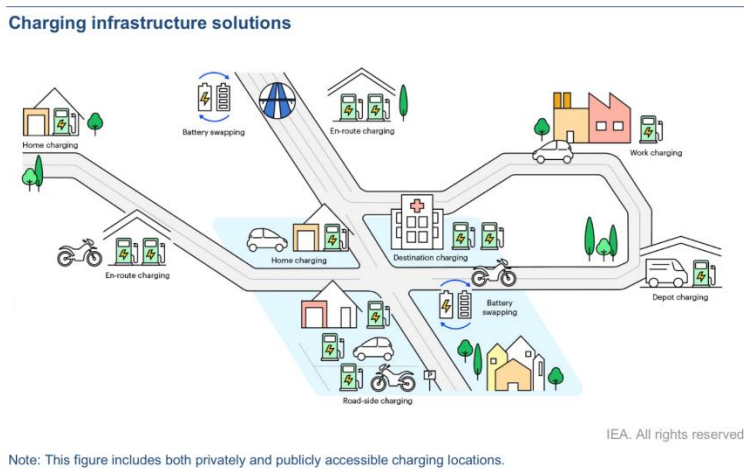
- (a) Deployment of a DC fast charging network to provide basic coverage and limit range anxiety
- (b) Deployment of an extensive AC charging network (private and public), allowing ubiquitous charging during long-stay (overnight or work) parking
  - (i) Private:
    - a. At home
    - b. Apartment dwellings
    - c. Workplace parkings
    - d. Company fleets
  - (ii) On public streets
- (c) Realizing/supporting opportunity charging: a top-up charging service during short stay:
  - (i) Retail chains
  - (ii) Public services
  - (iii) Guest parkings
- (d) Extend use cases and business models to provide better services and optimize business models, also to adapt to grid congestion issues and increase renewable energy usage:
  - (i) Additional services, facilities around charging stations (restrooms, working places, etc),
  - (ii) Smart charging,
  - (iii) V2G,

(iv) dynamic pricing etc.

25. PLACE HOLDER, Fastned good practice example to be added.

Figure VIII

### Overview of charging infrastructure solutions



Source: IEA (2022b)

26. According to IEA (2023), the projected deployment of charging infrastructure for both LDVs and HDVs is driven by several key trends:

- Cost: Home or depot (slow) charging is the preferred option for EV charging due to its affordability compared to fast charging.
- Convenience: Home or depot charging enables overnight or workplace charging, offering convenience to EV owners.
- Grid impact: Slow home or depot charging is compatible with smart charging and vehicle-to-grid operations, exerting less strain on the grid compared to faster charging options.
- Public and opportunity chargers: As the adoption of EVs increases, public and opportunity chargers will become more important, particularly because a smaller proportion of owners will have access to home charging as the EV stock grows.
- For HDVs, it is assumed that as technologies mature, more electric HDVs will be used for longer-range routes. Therefore, the deployment of public charging infrastructure should anticipate and support the electrification of these segments.

## F. Charging infrastructure Policies

27. EIB (2022) provides a non-exhaustive overview of possible objectives for rolling out public charging infrastructure. These may range from:

- Roll out several EV charging points within a specific timeframe.
- Establish a reliable functioning network of EV charging points with sufficient capacity to meet user demand.
- Achieve high levels of user satisfaction with public EV charging services.
- Reach areas with low user demand (current and/or projected).
- Create and/or maintain a competitive market for EV charging that drives fair prices for users.
- Integrate EV charging within a wider eco-mobility strategy.
- Use private sector capital and minimize the impact on public finances.

- Deploy private sector expertise and resources.

## G. Contracting models

28. Most countries have defined zero-emission transport goals as captured in each NDC. To reach these objectives, sufficient charging infrastructure needs to be in place. This requires a significant investment which need to be covered by private and/or public investments. EIB (2022) provides a comprehensive overview of the possibilities of governments to support this, such as:

- Policy — such as planning policy that enables EV charging infrastructure in public places, or tax breaks or other incentives that encourage EV uptake.
- Funding — including grants or loans made available to EV charging businesses.
- Partnering — working with private partners to secure the delivery of public EV charging infrastructure and/or services.

29. When entering in a public-private partnership several models are available to consider according to EIB (2022) as listed below:

- **Public contract:** The public authority controls the specification, installation, operation and use of the infrastructure. It retains most of the project risks from installation through to exploitation (including user-demand risk), contracting these out as required. The public authority finances the capital, operation and maintenance expenditure, and collects and retains revenues from users.
- **Joint venture:** The public authority and private partner share control of the infrastructure through a joint venture company they create. The risks are shared by the parties according to their stakes in the joint venture. The model is flexible on arrangements for financing, which might come from one or both parties or from a separate third party. User revenues are also collected and shared by the parties according to their stakes.
- **Concession:** The public authority retains some control over the specification, installation, operation and use of the infrastructure. The risks associated with installation through to exploitation (including user-demand risk) are typically transferred to the private partner, although risk allocation in the concession contract can be tailored to the specific circumstances. The private partner finances the capital and maintenance expenditure, with or without subsidies, guarantees or other financial support from the public authority. It also collects and retains user revenues, with or without sharing with the public authority.
- **Availability-based contract:** The public authority retains some control over the infrastructure, as in the concession model. Risks associated with installation through to exploitation are mainly transferred to the private partner, with the notable exception of user- demand risk. The private partner finances the expenditure, with or without financial support from the public authority, and is paid by the public authority over the duration of the contract only if the infrastructure is continually available for its intended use.
- **License:** The private partner controls the infrastructure and retains most of the project risks from installation through to exploitation. It finances the capital and maintenance expenditure and collects and retains user revenues. A license might include conditions and limitations regarding the private partner's actions, but typically allows more freedom than other partnering models (stating what the private partner may, rather than must, do).

30. The concession model is considered the most frequently used model in Europe, and is further elaborated upon by the EIB (2022). Also, other countries provide further guidance on this via regulation or guidelines. A typical description of a concession contract and the division of responsibilities:

- the private partner is responsible for installing, maintaining and operating publicly available EV charging infrastructure for a defined time period
- the private partner provides some (or all) of the financing required to design, purchase, install, operate and maintain the EV charging infrastructure
- the private partner has a direct relationship with users and collects and retains revenues from them
- the private partner's revenues fluctuate according to user demand and/or the standard to which it performs its obligations.

## H. Market models

### 1. Different market models

31. In each country and region, the electric mobility value chain has developed differently. The same holds for charging infrastructure. In the US, startups such as Tesla, Chargepoint, EVGo and Greenlots have been instrumental for 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.

32. Also, within Europe, each country has developed a different market model, driven by 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).

33. Two examples illustrate the current differences in approach in Europe:

- 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 need to conform to specific functional and technical requirements that assure full interoperability, transparent pricing etc. Although an open market, there is a strong central coordination to assure standardization, compliance and a user centric approach.
- 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<sup>14</sup>), 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.

34. 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. But 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.

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<sup>14</sup> [https://epub.wupperinst.org/frontdoor/deliver/index/docId/7679/file/7679\\_Wagner.pdf](https://epub.wupperinst.org/frontdoor/deliver/index/docId/7679/file/7679_Wagner.pdf)

## 2. Harmonization across market models

35. In each of these regions, and across the different continents, a market for charging infrastructure has appeared. The type of market – the regulatory framework, the roles and responsibilities, the openness and interoperability, the fiscal and subsidy framework – differs per region and per country. Also in Europe, many different market models exist with different roles of public government, ranging from providing a strong regulatory framework and role definition that each commercial actor needs to adhere to, to a loose set of regulations that leaves a room for a variety of public-private contracts.

36. Within each market model, both public and private actors are invested in improvements and innovations; the market is young, it combines both transport, energy, spatial and digital ingredients into a variety of charging services. These services consist of both hardware, software and data components that each require functional, quality and interoperability requirements that will be addressed below.

## 3. An open and interoperable market

37. Openness and interoperability are fundamental aspects of a market-driven sector like electric mobility and charging infrastructure. However, a closer examination is required to fully understand the implications of these terms on these developments.

38. Interoperability is a concept that refers to the ability of systems or actors to operate together. Various definitions of interoperability exist.

39. 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”.

40. The Intelligent Transport Systems directive of the European Commission (ITS 2010/40/EU)<sup>15</sup> defines interoperability as “the capacity of systems and the underlying business processes to exchange data and to share information and knowledge”.

41. Interoperability as a concept has been successful in sectors like telecommunications and IT, where sharing relevant information between service providers allows users to benefit seamlessly from infrastructure and services, regardless of the specific hardware or subscriptions in use. The benefits of interoperability include:

- Reduction of installation and integration costs, mainly due to not requiring any conversion/translation services/components.
- Efficient scale-up of services through reuse of interoperable components.
- Efficient development of new services 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.

42. When systems are interoperable, they may still make use of proprietary tools, standards or protocols to achieve interoperability. This can result in a certain cost, Intellectual Property (IP) claim or proprietary development process. A benefit of using a proprietary standard can be that they can be quickly implemented and used. A disadvantage is that they can cause restrictions and dependencies in the development of standards, and thus hinder the growth of a market sector.

<sup>15</sup> <https://eur-lex.europa.eu/legal-content/EN/TXT/HTML/?uri=CELEX:32010L0040&qid=1686806748402>

43. The World Trade Organization's Committee on Technical Barriers to Trade (WTO TBT) defines six aspects of openness for open international standardization processes (WTO, 2000):

- Transparency in communication (regarding documentation on proposal for standards and final standards).
- Openness in development (open membership at every stage of standardization process).
- Impartiality and consensus in decision making (no privilege or favoring interests of a particular party).
- Effectiveness and relevance (facilitating international trade).
- Coherence (no duplication of or overlapping with other the work of other standardization bodies).
- Inclusion, specifically addressing concerns of developing countries (developing countries should not be excluded de facto from the process).

#### **4. An open market for electric vehicle charging and 'layers of interoperability'**

44. 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 (such as data exchange through open standards, or government-owned data reporting). Policymakers and competitive authorities should periodically assess future developments to ensure a competitive marketplace. It is useful to assess all parts of the value chain and distinguish between the different 'layers' where market actors interact.

45. The Smart Grid Architecture Model, developed by the European standardization organization CEN-CENELEC,<sup>16</sup> identifies different 'layers of interoperability' needed for a successful market-driven sector, including the:

- Hardware layer focuses on interoperability of connectors and plugs.
- Communication layer, involves seamless communication between hardware and software systems in order 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.

46. 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, roaming) and efficient back-end processes for installation and operation of charging infrastructure, making use of different manufacturers, operators, DSO's and construction companies.

#### **5. Direct payment, subscriptions and roaming**

47. The deployment of charging infrastructure has started with Charging Point Operators (CPOs) offering access to their charging networks through either a direct payment model or a subscription-based (post-payment) model. With the emergence of a market-driven

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<sup>16</sup> [https://www.cenelec.eu/media/CEN-CENELEC/AreasOfWork/CEN-CENELEC\\_Topics/Smart%20Grids%20and%20Meters/SmartE20Grids/reference\\_architecture\\_smart\\_grids.pdf](https://www.cenelec.eu/media/CEN-CENELEC/AreasOfWork/CEN-CENELEC_Topics/Smart%20Grids%20and%20Meters/SmartE20Grids/reference_architecture_smart_grids.pdf)

operational model and multiple CPOs providing charging services, the role of an e-Mobility Service Provider (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.

48. Direct payment solutions utilize existing interoperable payment systems such as credit card terminals, QR codes, and in-app payments etc. 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 cost for charging equipment. Moreover, there is minimal interaction between the EV driver and the CPO regarding the acquired charging service.

49. 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.<sup>17, 18</sup>

50. 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.

51. 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.

52. 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.

53. 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.

54. Roaming in EV charging requires a contract-based model and necessitates layers of interoperability to ensure an optimal roaming service. Implementing a contract-based model with interoperable EV roaming offers several benefits:

- EV drivers can charge their vehicles at any charging network without the need for multiple access methods, both within a country and across countries.

<sup>17</sup> <https://www.aveure.org/publications/item/2023/04/15/AVERE-position-paper-on-the-upcoming-proposal-for-a-new-Payment-Services-Directive-PSD-II>

<sup>18</sup> <https://www.chargeurope.eu/s/The-need-to-remove-PIN-pad-obligations-for-EV-charging-payments-2-March-1.pdf>

- CPOs can expand their customer base, increasing charging sessions, and enhance their business case.
- CPOs can exchange information with user profiles and offer smart charging and other services, optimizing EVs as flexible storage assets and maximizing the use of renewable energy.
- Distribution System Operators (DSOs), through CPOs, gain better control over grid congestion and peak times, resulting in reduced grid investments.
- Public governments can efficiently invest in public charging networks and provide optimal charging experiences for citizens, thereby accelerating the deployment of zero-emission transport.

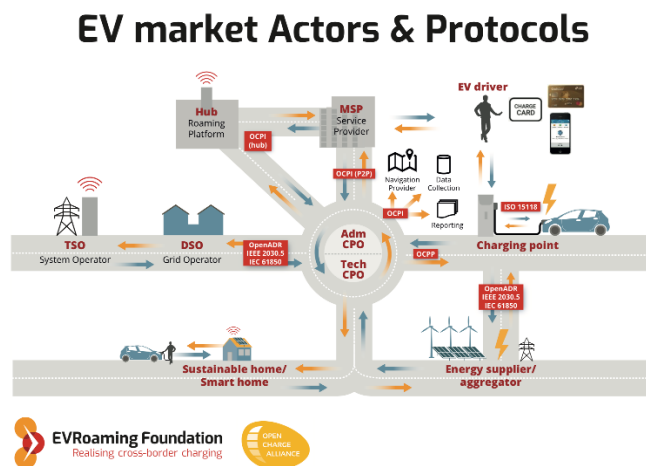
55. As stated by the UK government, “Implementing roaming across networks means consumers can access all public charge points with one membership card or smartphone app”.<sup>19</sup> In France, decree n° 2017-26 mandates that public charging infrastructure owners make their charging stations open to eRoaming, either via direct links or roaming platforms. Public charge points must be accessible through direct payment or an MSP contract, at the EV driver’s choice.

56. California has decided to require at least one common roaming protocol to facilitate roaming agreements,<sup>20</sup> but is also specific in its choice of OCPI as this roaming protocol. On 29 May 2020, the US State of California filed legislation to facilitate roaming agreements. The Californian Code of Regulations requires that “No later than July 1, 2021, the EVSP shall meet, at a minimum, and maintain the “California Open Charge Point Interface Interim Test Procedures for Networked Electric Vehicle Supply Equipment for Level 2 and Direct Current Fast Charge Classes,<sup>21</sup>” adopted April 15, 2020, and incorporated by reference herein, for each applicable EVSE. This does not preclude the additional use of other communication protocols.”

## 6. An open and interoperable market model

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

Figure IX  
EV market Actors & Protocols



Source: EVRoaming Foundation.<sup>22</sup>

<sup>19</sup> [www.gov.uk/government/consultations/the-consumer-experience-at-public-electric-vehicle-chargepoints/the-consumer-experience-at-public-chargepoints](http://www.gov.uk/government/consultations/the-consumer-experience-at-public-electric-vehicle-chargepoints/the-consumer-experience-at-public-chargepoints)

<sup>20</sup> [https://ww2.arb.ca.gov/sites/default/files/2020-06/evse\\_fro\\_ac.pdf](https://ww2.arb.ca.gov/sites/default/files/2020-06/evse_fro_ac.pdf)

<sup>21</sup> <https://ww2.arb.ca.gov/sites/default/files/barcu/regact/2019/evse2019/attbtestprocedure.pdf>

<sup>22</sup> [www.evroaming.org](http://www.evroaming.org)



58. 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.

59. An overview of most widely used charging protocols and standards are described below:<sup>23</sup>

- Open Charge Point Protocol/ IEC 63110 - 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.

(Source: Open Charge Point Protocol 2.0.1, Open Charge Alliance, [Online]. Available at: OCPP 2.0.1, Protocols, Home - Open Charge Alliance)

- Open Charge Point Interface/ IEC 63119 – Between the charging station operator and the mobility service provider: Open Charge Point Interface (OCPI) protocol is used to exchange information between the CSO and the mobility service provider (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 and supports the exchange of information on locations, tariffs, authorizations and charging transactions. It also supports smart charging through the management of charging profiles. (Source: EVRoaming.org)
- ISO15118 / CHAdeMO – 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.

## 7. User friendliness

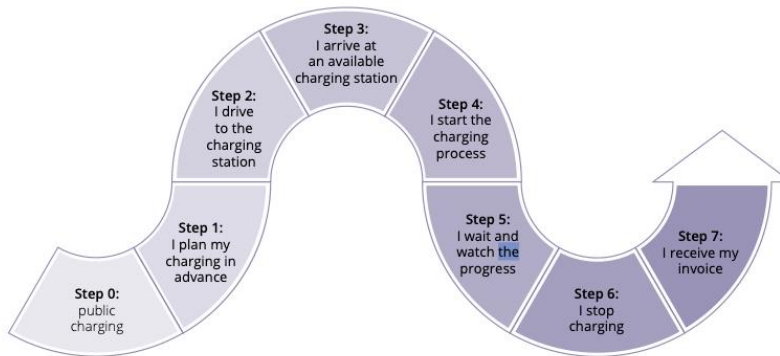
60. The deployment of charging infrastructure in the EV sector follows a similar pattern to other innovative and market-driven technology sectors. It transitions from a technical paradigm (“can we make it work”) to a functional paradigm (“what kind of charging is needed”) and ultimately towards a service proposition (“what does the EV driver need”).

61. The focus on user friendliness can be made concrete by defining a uniform customer journey, by identifying and measuring the quality of service, and by focusing accessibility beyond the default user groups.

62. To gain a comprehensive understanding of EV driver needs, various instruments are available from the field of service design. One such tool is the customer journey, which provides a systematic approach to understanding the customer experience and can be enhanced by incorporating specific targets such as response time and quality.

<sup>23</sup> (Source “Position Paper on Open Markets & Open Protocols” (June, 2021), NAL Working Group Open Market & Open Protocols, Netherlands)

Figure X  
**Definition of the customer journey**



Source: NKL (2021)

63. The key findings derived from the development of the customer journey are as follows:

- EV drivers are proactive and attentive, investing a significant amount of time in gathering information. It is important to note that this level of proactive research may not be expected from future drivers who fall into the late majority category.
- Most charging activities occur at familiar locations.
- EV drivers have confidence in the availability of charging stations, thanks to relatively long driving ranges and the abundance of (rapid) charging infrastructure.
- The primary selection criteria of charging stations for EV drivers are availability, charging speed and costs.
- There is a vast amount of information available to EV drivers, originating from diverse sources but with varying levels of accuracy. Quality of information is a key differentiator.
- Backup plans and alternative checks are commonly sought when a charging card or station fails to function or is unavailable, as this information is not always available.
- Price transparency for charging services is considered sufficient.
- There are concerns regarding potential price increases in the future.

64. Another approach to capturing the customer experience in specific service KPIs is by evaluating the expected service level for EV drivers. Although this approach is still rarely utilized, it offers valuable insights.

Box 1

**A benchmark to determine the quality of service of a charging network**

In 2022, A service benchmark has been developed to measure the user-friendliness of public charging. The National Knowledge Platform for Charging Infrastructure in the Netherlands (NKL) has developed an overview of KPI’s that together make up the quality of service for a charging network. The KPI’s have been measured, both via a field test and desk research, and have delivered a benchmark on ‘service’ for public charging operators in the country.

The longlist of potential indicators to define user-friendliness has been drawn up, based on desk studies and via a questionnaire. The following KPI’s have been considered most critical:

- (a) Charger reliability
- (b) Charger availability
- (c) Incorrectly parked fuel car

- (d) Availability in apps
- (e) Location in apps
- (f) Helpdesk availability
- (g) Helpdesk expertise
- (h) Contact information of the helpdesk
- (i) User-friendliness of the charger
- (j) Accessibility of the charger
- (k) Verifiability of the invoice
- (l) Maximum charging speed
- (m) User input for “smart charging”
- (n) Price transparency
- (o) Renewable electricity provided.

Source: NKL (2021b)

65. Part of the service definition of a charging station is the reliability. This can be measured by the so-called up-time, a percentage per annum and/or per month to assure the technical availability of a charging station.

66. Several malfunctions can be encountered when attempting to charge an EV at a public charger. To improve the reliability of publicly accessible charging infrastructure, the different types of failures and their causes need to be understood, as well as who is responsible for this. Four key steps should be considered when defining a reliability standard and are presented in Figure XI.

Figure XI  
Four key steps for defining a reliability standard



Source: ICCT.<sup>24</sup> Accessed on 7 June 2023.

67. Several jurisdictions have begun developing charging reliability standards. These standards include uptime requirements, reporting obligations, and data accessibility to improve overall charging network reliability. Jurisdictions can benefit from knowledge sharing and alignment on reliability standards.

<sup>24</sup> <https://theicct.org/publication/public-charging-reliability-mar23/>

Box 2

**Addressing reliability of charging infrastructure in the United States**

The ICCT<sup>25</sup> in collaboration with the ZEV Alliance has provided a briefing on reliability of charging infrastructure. One driver for this priority was a 2022 University of California, Berkeley study which found that only 77 per cent of public chargers in the San Francisco Bay area were functional.

Six types of malfunctions were found in this study:

- broken connector
- blank or non-responsive screen
- error message on screen
- connection error
- payment system failure
- charge initiation failure.

The California Energy Commission addressed this topic in a workshop in 2022, where the following causes of unreliability of DC charging were given by the company Electrify America.

**Table 3  
Cause of DC fast charging unreliability**

<i>Cause of DC fast charging unreliability</i>	<i>Explanation</i>
Hardware reliability	This includes the failure rate of hardware components and the time it takes to replace them. The responsibility to improve this mostly falls on charge point manufacturers. This can be monitored through uptime data.
Vehicle interoperability	Standardization of vehicle plugs and charging connectors across makes and markets is inconsistent and can lead to charging failure. This can be monitored through an assessment of charge success rates.
Global supply chain disruptions	This results in industry-wide parts shortages and increased lead time to replace non-functioning parts.
Service operations	There is a need for enhanced real-time remote monitoring diagnostic capabilities and a decrease in repair time.
Network IT management systems	These systems allow charge point operators to communicate with and manage the charge points. The rapid growth of charger utilization and the customer base can put stress on the IT structure.
Payment authorization	This can be an internal or external payment system failure and remains a top driver of unreliability.

*Source: ICCT (2022)*

68. Regulation around reliability is currently being investigated in several countries and regions, where the current focus is mostly on providing uptime requirements in contracts and improving reporting on reliability.

<sup>25</sup> <https://theicct.org/wp-content/uploads/2023/03/public-charging-reliability-mar23.pdf>

69. Today it is not guaranteed that charging stations are accessible for everyone. No uniform regulation is available, leaving it up to the contracting authorities and operators to fill this gap.

70. The European Commission, through STF, focuses to identify the main issues and needs to be considered by public authorities at three different levels:

- Hardware: pole/charging station's equipment
- Associated parking spaces and surrounding environment, and
- Distribution/location of accessible recharging poles/stations & parking spaces.

71. The groups or use cases that will be addressed with this initiative, are:

- People who drive as well as people who do not drive
- Different kind of disabilities - blind, wheelchair and paraplegic
- Parking infrastructure with a 'normal car' (in that case, space is not much of an issue, but other aspects are to be considered for accessibility)
- Parking infrastructure with an adapted car, special fleets
- Mobility hubs, and
- Recommendations from this STF task force may result in additional regulation from the European Commission (AFIR) or could private standardized specifications and requirements for contracting authorities.

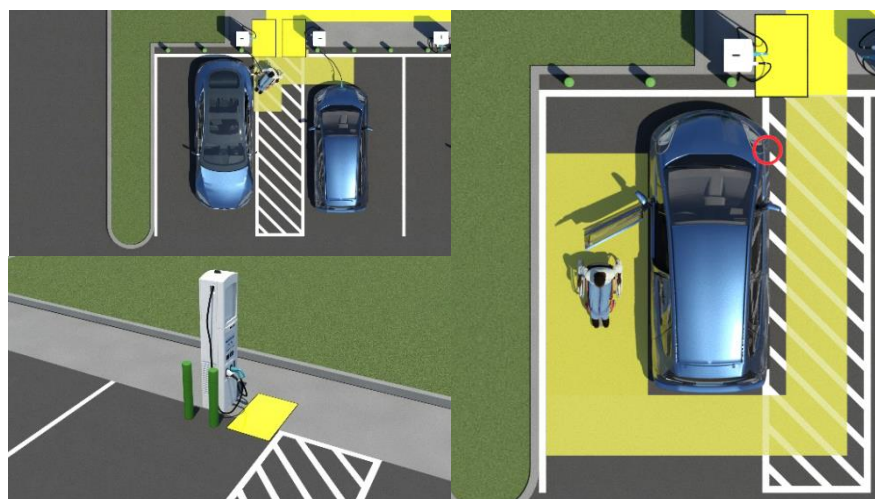
Box 3

### U.S. Design Recommendations for Accessible Electric Vehicle Charging Stations

The U.S. Access Board, an independent federal agency, has provided a technical assistance document to assist in the design and construction of EV charging stations that are accessible to and usable by people with disabilities. These recommendations are not legally binding but provide technical assistance on the matter.

Some key elements that are being addressed:

- (Accessible) Charging spaces differ from parking spaces, due to the charging requirements and the variation of charging configurations (location of inlet, usage instructions, etc)
- EV charging stations are often unattended, requiring more independent use than e.g. petrol stations:
  - Physical accessibility
  - Accessibility of communication features.



Source: U.S. Access Board.<sup>26</sup> Accessed on 7 June 2023

## 8. Alternative charging solutions for passenger vehicles

72. The previous sections were mainly applicable to the context of passenger vehicles and assumed regular charging stations with 2 charging points. Multiple other charging solutions are available to accommodate a charging use case for a specific context. Some are well developed; others are still innovative in their approach.

### (a) Charging hub or plaza

73. A charging plaza comprises more than two charging stations for electric vehicles which are not connected to the grid separately and share a single connection.

74. A number of factors play a role in making the choice between a charging plaza and a charging station (NKL, 2021b):

- Spatial planning: limiting the number of objects in public space.
- Streamlining traffic flows: to organize the flow towards a charging facility.
- Scalability: for a limited extra effort, many charging points can be installed.
- Service to users and reliability of charging point availability: there is more certainty that a charging point is available to use.
- Stimulating the use of electric vehicles: a charging hub is more visible and recognizable, thereby providing more certainty for (potential) EV drivers.
- Financial considerations: the business for a charging hub has a better outlook with take-up of EVs.
- Combination with a mobility hub: a charging hub is a logical location for providing shared cars or bike and thus function as a mobility hub.
- Charging process management: with multiple charging points on a single grid connection, the electricity demand can be managed more effectively and reduce grid congestion issues.

Figure XII

### Schematic version of technical versions of a charging plaza

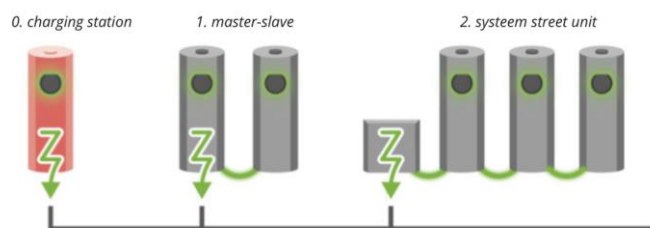


Figure 3 - Schematic representation of 0. standard charging station and the two different technical versions of charging plazas: 1. master-slave structure and 2. system street unit.

Source: NKL (2021b)

### (b) Integrated and underground charging

75. On-street charging is considered the most likely solution for urban EV drivers who are unable to install chargers at their homes. But especially in public space, spatial development policies may include the ambition to limit the number of objects in public space. In that case, innovative solutions can be considered to integrate the charging function in existing objects. Multiple solutions are available to integrate charging points into street furniture. Considerations are:

<sup>26</sup> <https://www.access-board.gov/tad/ev/>

- Less clutter, less objects on street
- Integration of functions in public space
- In addition, underground charging solutions are available to prevent any visible disruption around monumental buildings, architectural areas etc.

76. Technically, these solutions can be considered regular charging stations with one or two outlets, or a charging plaza with multiple outlets on a single grid connection. From a functional perspective, there may be limitations regarding regulatory requirements (does a fixed charging cable need to be provided), safety issues (is this a safe charging location), user friendliness (is the charging point visible, is it easily accessible), etc.

77. Roadside Street EV Car Charging Cabinets: Deutsche Telekom announced plans to turn 12,000 street cabinets<sup>27</sup> into charging stations. Each device will supply per hour two vehicles with enough power to reach a range between 50-75 km. Pilot projects have been implemented in the cities of Bonn and Darmstadt with the aim to build a nationwide network by upgrading parts of its existing telecommunications infrastructure to become charging stations.

78. Lamppost charger: Integrating a charging point with a lamp post is a specific example of curbside charging that has reached some level of maturity, as it has been deployed in cities worldwide in pilots or smaller contracts. Some considerations need to be taken into account though when considering this, as lamp posts are usually not configured to act as a charging point:

- The amperage may differ, resulting in a low power output.
- There is no metering device available per lamp post, bypasses are needed to ensure a metered charging session (e.g. similar to a wallbox home charger).
- Lamp posts often have a single grid connection for multiple posts, limiting capacity.
- Lamp posts are not always located at proper parking locations.
- When integrating the function of a lamp post with a charging point, a useful perspective is to consider this as a charging station (or charging plaza) with additional lamp post functionality, or a wall box charger added to a lamp post, rather than the other way around.

79. Wireless electric vehicle charging which is based on the principle of inductive charging whereby a magnetic coil in the charger hidden beneath the road surface transfers electricity through an air gap to a second magnetic coil which is fitted underneath the vehicle. It suffices the vehicle is parked in the immediate proximity of a charging point.

## 9. Charging infrastructure for electric busses

80. Determining the charging strategy is of utmost importance as it impacts timetable planning and costs. It should consider the balance between charging in depots and on-road “opportunity” charging. The selection criteria should include factors such as the total cost of ownership (TCO), vehicle range, and infrastructure feasibility. Range is particularly essential for transit agencies considering which routes the electric buses will drive on.

Table 4  
**E-bus charging technology**

<i>Charging System</i>	<i>Plug-in charging (AC or DC)</i>	<i>Opportunity charging (DC only)</i>
Charging locations	Charge in depots via cable	On-road and/or in depots via pantographs
Batteries	High battery capacity	Lower battery capacity
	Higher battery weight	Lower battery weight

<sup>27</sup> Explanation: Weatherproof/ environmentally controlled streetside cabinets housing transmission and telecommunication equipment.

<i>Charging System</i>	<i>Plug-in charging (AC or DC)</i>	<i>Opportunity charging (DC only)</i>
	No need for fast charge	Faster charge rate
Planning	No planning issues around depot chargers	Planning and amenity issues around on-street chargers
Range	Lower range than diesels Up to 250 km per day	Addresses range issues but requires regular in-service charging Maximum of 190 km between charges depending on installed battery capacity
Batteries	High battery capacity	Lower battery capacity
“Live” cities and towns	London >500 buses and rising Aberdeen Brighton, Harrogate, Nottingham, Salisbury	The Netherland >1,000 buses
Definition	AC = alternating current motor and traction package DC = direct current motor and traction package	Charging at high speed via overhead or below vehicle connectors
Charging rate	40-80 kW (80 kW assumes two charges per bus, per BYD) Plug-in charging	Depot 50-150 kW On-street 300-600 kW Plug-in or opportunity charging
Capital cost – charger on street	Not available	€280,000-340,000 (2020 prices)
Capital cost – in depot charger, excluding installation costs	€8,000-13,000	€28,000
Charging time	3-5 hours per vehicle	3-3.5 minutes per vehicle assuming 100 kW charger

*Source:* EBRD (2021)