Ref. Ares(2024)3784845 - 27/05/2024

AI-informed Holistic Electric Vehicles Integration Approaches for Distribution Grids

D4.2

EVSEs use classification and KPIs

November 2025 (M18)

Co-funded by the European Union

This project has received funding from the European Union's Horizon Europe research and innovation programme under grant agreement No. 101160665.

DELIVERABLE DETAILS					
Project	AHEAD	Grant Agreement	101160665		
Deliverable Type (R, DEM, DEC)	R	Deliverable Title	EVSEs use classification and KPIs		
Status	Final	Month due	M18	Date	30/11/2025
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Dissemination level	PU - Public				

HISTORY OF CHANGES				
Document history	Date	Version	Submitted by	Comments
	01/09/2025	0.1	UPT	Initial draft sent for WP revision
	16/10/2025	0.2	UPT	Draft sent for Consortium revision
	13/11/2025	0.3	ELBIL, INESC ID	Draft sent back with comments
	25/11/2025	0.4	UPT	Final draft with all comments addressed
	27/11/2025	1.0	POLIMI	Uploaded document

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EXECUTIVE SUMMARY

This deliverable develops a framework for classifying Electric Vehicle Supply Equipment (EVSE) and identifying the Key Performance Indicators (KPIs) that best capture their technical, economic, social, and environmental performance. The work addresses the growing complexity of EV charging ecosystems by aligning the needs of diverse stakeholders with suitable categories of EVSE and measurable indicators.

The report aims to provide a comprehensive classification of EVSE types and a structured set of KPIs that reflect both operational performance and stakeholder expectations. These elements are designed to feed into future decision support tools that will guide optimal integration of charging infrastructure into energy distribution grids. The work is divided in three main parts:

1. Stakeholder Analysis

   A wide range of stakeholders are examined, including policy makers, public utilities, grid operators, EV users, manufacturers, operators, and service providers. Each group's interests, expectations, and strategies are mapped, with particular focus on potential points of convergence and divergence. A stakeholder survey, collected data on charging priorities such as infrastructure coverage, charging speed, affordability, sustainability, and user experience.

2. EVSE Classification Framework

   The report establishes a classification scheme that groups EVSE according to technical characteristics such as alternating current (AC) vs. direct current (DC), power levels, smart features, vehicle-to-grid (V2G) readiness, user contexts (i.e., residential, workplace, public urban, highway corridors, depot/commercial use) and grid impact (i.e., low-voltage vs. medium-voltage connections, load clustering, flexibility potential). This framework enables targeted planning, ensures infrastructure aligns with real-world use cases, and helps anticipate grid integration challenges.

3. Key Performance Indicators (KPIs)

   A structured KPI set was developed and clustered into categories. The set covers availability and reliability of charging infrastructure, efficiency and flexibility, including smart charging and V2G, grid and market compliance, such as protocol adherence and energy market participation, cybersecurity, safety, and service quality, financial, social, and environmental impacts, such as affordability, equity, and emission reductions.

In addition, the reports map the correlation between KPIs, EVSE clusters, and stakeholder groups, to provide a tool to decision-makers. That is, by selecting the access type, location, power and the availability of services, the tool can provide the most significant KPIs for each stakeholder group. These KPIs shall be used by decision makers to quantify the profitability of the new charging equipment or integrate them into different other strategies.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

1 INTRODUCTION

1.1 Scope and Objectives

The goal of WP4 is to define grid models and spatial models that will enable the participation of electric vehicles (EVs), HEVs, and vessels in grid services. A key objective within WP4 is to establish a comprehensive set of parameters and key performance indicators (KPIs) to categorise the EVSEs. This objective is achieved by Task 4.2 and deliverable D4.2 titled "EVSEs use classification and KPIs" documents the work done.

The increasing use of EVs and respective charging equipment has enlarged the pool of stakeholders and users interested in EVSEs. KPIs are a tool to better fit the needs of stakeholders by choosing the right charging equipment. Depending on the intended use of the equipment and the stakeholder needs the set of KPIs may vary.

The scope of the deliverable is to provide a comprehensive set of KPIs that facilitate the categorization of EVSEs based on their operational characteristics. To achieve this categorization these main tasks are accomplished:

- Stakeholder categorization

  To better understand the needs of stakeholders and the criteria they are more interested in EVSEs, stakeholders are categorized to define a common set of characteristics for a whole group of stakeholders.

- Definitions of stakeholders' requirements

  For each group of stakeholders, a set of relevant KPIs is identified. This set is used in the classification framework to generate the relevant KPIs based on the intended use of the equipment. The requirements are defined based on the Scientific Literature and a Survey distributed to stakeholders. The results of the survey are presented in Section 2.2.

- Definition of a classification framework

  In this work the framework is formulated as a selection process in which the user provides preliminary information on the EVSE and based on the stakeholder group the most suitable set of KPIs is provided. These can be used in decision support tools to evaluate the effectiveness and convenience of the charging equipment.

- Definition and clustering of the KPIs

A comprehensive list of KPIs with their explanation and calculation formula is provided in Section 4. In addition, the correlation between KPIs, stakeholder groups and EVSE clusters is provided. Table 11 serves as a selection tool which provides the most interesting KPIs for a given EVSE cluster and stakeholder group. This shall be integrated with the decision support tool which will be developed in Task 4.4.

1.2 Structure of the document

The document is organized in five main chapters:

- **Chapter 1 – Introduction** outlines the scope, objectives, and structure and clarifies the relationship between this document and other deliverables within the project.
- **Chapter 2 - Stakeholders and EVSE Requirements** provides a comprehensive review of the stakeholder groups involved in EVSEs market and the requirements that each group expects from charging equipment. The classification is based on literature as well as the survey results.
- **Chapter 3 - EVSE Classification framework** defines a classification scheme to select the most appropriate KPIs based on the required characteristics and the stakeholder involved in the decision process.
- **Chapter 4 - Key Performance Indicators** provide a comprehensive list of KPIs which are relevant to EVSEs. These indicators are selected from a thorough literature analysis and are complemented with insights from survey responses.
- **Chapter 5 - Conclusions and recommendations** synthesize the key findings of the deliverable and offers recommendations for the key indicators to consider when planning new charging equipment locations.

1.3 Relationship with other deliverables

Task 4.2 has the objective to identify a set of relevant parameters and KPIs that best classify the operational characteristics of EVSEs. These KPIs are used in the development of a decision support tool necessary to define the strategies of EVSE infrastructure expansion. The decision support tool will be developed in Task 4.4 and will make use of some of the KPIs identified in this task to formulate an optimal strategy for the development of EVSE infrastructure within urban environment using AI-based algorithms. This integrated approach ensures that the relevant KPIs will be coordinated effectively, enabling grid operators to make informed decisions and fine-tune their strategies for grid management.

2 STAKEHOLDERS AND EVSE REQUIREMENTS

In this section, we define the main stakeholders interested in Electric Vehicle Supply Equipment (EVSE). Section 2.1 organizes stakeholders in groups based on their interests and focus area, then we provide a set of key factors for each group. Section 2.2 describes the findings of a survey conducted on different stakeholders. In Sections 2.3 and 2.4 we provide a comprehensive list of the stakeholders, defining their main interests, agreement and disagreement points.

2.1 Main stakeholder groups

Stakeholders in the EVs perspective, are the persons, institutions, organizations, formal and non-formal groups which are interested, can be affected, or which could influence the policies or actions related to EVs, [1]. Stakeholders can be categorized in seven main groups as graphically represented in Figure 2.1, [2]

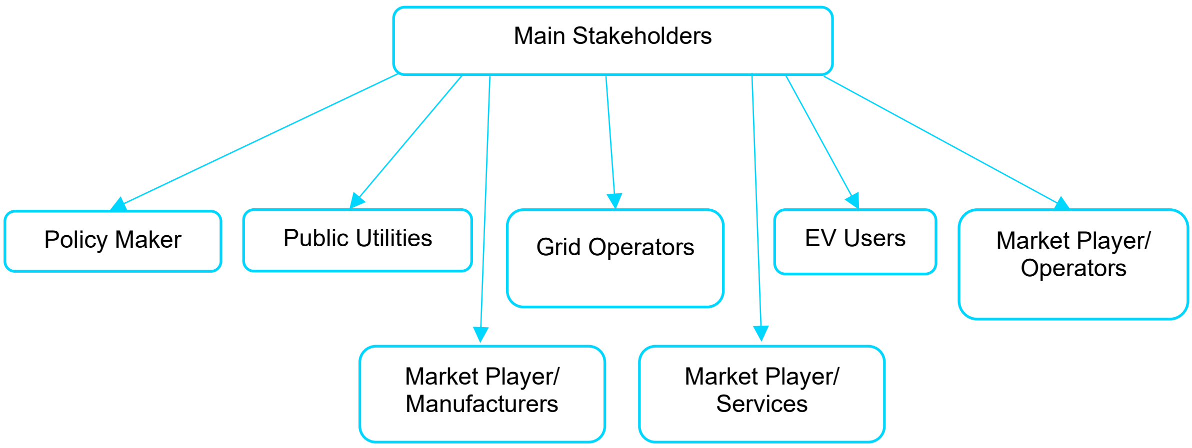


Figure 2.1: Stakeholder groups.

In the following a brief summary is provided on each group:

- **Policy Makers –** They are required to make medium- and long-term strategic choices regarding the deployment of the charging infrastructure. Since the payback period for investments in emerging technologies is typically long, the limited availability of financial resources and time forces them to set priorities for funds allocation. In this context, various charging technologies both established and emerging are competing for policymakers' attention and investment. On this context, policy makers include sub-stakeholders like research/education, environmental and consumer organization, regulators etc. in other words all of medium- and long-term decision-makers in the field.

- **Public Utilities –** They are responsible for managing roads, traffic, and public transit systems such as trains, buses, and metros. Public utilities play a crucial role in the shift toward sustainable mobility. They have to ensure efficient transportation networks and lead the transition to zero-emission fleets by integrating the necessary charging infrastructure to support these operations.
- **Grid Operators –** Organizations that own and operate power generation and power transmission assets. Grid operators (GO) are responsible for producing and/or transporting electricity and play a central role in electricity markets.
- **System Operators** – This category covers Transmission System Operators (TSOs) and Distribution System Operators (DSOs) among others, and deliver multiple services, i.e., transmission stability, security etc. With the increasing integration of EVs particularly through V2G concepts, generation companies (GENCOs) face both new opportunities and challenges. EVs can provide ancillary services and influence generation dispatch, reshaping the dynamics of electricity production and system management. EVs however, can also contribute to solve a problem system management, ie. energy storage, when collaborating with all the other resources that are used for this service.
- **Users –** Individuals or companies that own EVs, users of conventional non-electric cars, and organizations or fleet operators managing commercial vehicles, including battery-electric trucks and other heavy-duty vehicles. These groups play distinct roles in mobility, with commercial operators particularly requiring specialized charging solutions to enable efficient, cost-effective logistics and freight operations.
- **Market Player/Operators –** These entities develop and operate smart control platforms, coordinate EV charging and discharging, and aggregate distributed flexibility to provide ancillary grid services. They use data, real-time algorithms, and communication protocols to enable EVs as dynamic storage assets. Some entities design and manage local flexibility market platforms, acting as intermediaries between DSOs and aggregators, coordinating auctions, bid submissions, and market clearing. Independent market operators handle flexibility market management without revealing sensitive DSO information, collecting service requests, running auctions, and evaluating bids. Charging infrastructure operators manage EVSE and related services, selling energy to EV drivers and overseeing daily station operations.
- **Market Player/Manufacturers –** Charging station manufacturers ensure that their stations are safe and comply with international standards. Meanwhile, car manufacturers either

develop their own charging networks or collaborate with charging point operators to provide drivers with adequate and reliable charging infrastructure.

- **Market Player/Services –** They provide guidance to stakeholders and make strategic decisions on EV charger placement. Charging Point Operators (CPOs) together with roaming operators usually handle driver billing. In some cases, they provide loans or financing for EV charging projects, aiming for profitable growth. In other cases, can governments provide subsidies, yet varying significantly across EU member states. Property owners and managers integrate charging infrastructure to optimize space, boost energy efficiency, attract tenants, and enhance property value.

2.1.1 Main stakeholders' interests, expectations and strategies

The transition towards electric mobility involves a wide range of stakeholders with complementary roles: **policy makers** drive the shift through regulations, incentives, and infrastructure planning; **public utilities** and **grid operators** ensure reliable and sustainable integration of charging networks into energy systems; **users** create demand by seeking affordable, efficient, and convenient EV solutions; and **market players**, manufacturers, and service providers deliver innovation, expand networks, develop sustainable supply chains, and enhance the overall user experience. Together, these actors shape a collaborative ecosystem where policy, technology, infrastructure, and consumer behaviour align to accelerate zero-emission transport. In Table 1 a summary of stakeholder groups with their interests, expectations and strategies is provided [3].

In the following sections the main aspect of interested related to stakeholders are briefly discussed

Table 1: Stakeholder group interests, expectations and strategies

Group	Interests	Expectations	Strategies
Policy Makers	• Cut emissions • Improve air quality • Boost economic growth	• Charging infrastructure investments • Supportive regulations • Battery sourcing and supply chain facilitator • Strategic planning and global collaboration.	• Financial incentives • Infrastructure development • Regulatory measures
Public Utility	• Reduce CO_2 emissions • Greater service reliability • Higher passenger satisfaction • Integration of charging infrastructure at transit hubs.	• Facilitate a seamless shift to zero-emission public transit deploying reliable and accessible charging infrastructure • Fleet electrification and smooth integration with urban mobility systems. • Provide safe, affordable road transportation • Maintaining customer satisfaction • Offering diverse travel options.	• Prioritizes expanding charging infrastructure—particularly for homes and multi-unit residences • Upgrading the grid to support rising demand • Promoting off-peak charging through incentive programs • Advancing V2G solutions that allow EVs to function as flexible energy storage assets.
Users	• Cutting travel-related emissions and backing policies that phase out petrol and diesel vehicles. • Reduction of notice pollution which has a great impact in big cities • Vehicle operating cost reduction	• Budget-friendly vehicles • Longer battery ranges • Broader and faster public charging options. • Lower charging costs, especially in public chargers.	• Shaping policy by providing feedback on infrastructure and incentive programs • Driving demand for more charging stations, interoperability standards, and a wider selection of affordable electric vehicles. • User-led innovation plays a key role, with advocacy groups and consumer collectives championing better access to data, standardized pricing, and real-time information on charger availability to improve the overall EV ownership experience.
Grid Operators	• Maintaining grid stability by balancing supply and demand at the local and national level • Expanding responsibilities to include the management of public charging infrastructure.	• Widespread adoption of electric vehicles may strain grid stability and require overall grid upgrades • Smart-charging systems can help mitigate grid stability issues	• Engage in pilot projects to study charging behaviour and grid impact • Build public charging infrastructure while advocating for long-term management responsibilities • Create systems to optimize charging.
Market Player/ Operators	• Grid support services such as peak demand management and load balancing • Ensuring flexibility and safety in charging infrastructure for EV users.	• Shape the overall charging experience by overseeing and coordinating the key aspects of the EV charging process. Flexible EV. • Enable dynamic charging control, allowing adjustments in timing and power flow to align with grid demands, renewable energy supply, and user preferences. • Optimizing EV charging by aligning it with available renewable energy.	• Build roaming agreements across operators • Develop flexible pricing models and loyalty programs • Strategic planning and rollout of electric vehicle (EV) charging networks. • Selecting locations that maximize accessibility and meet demands.

Group	Interests	Expectations	Strategies
			• Managing operations in real time by creating and sustaining a network that links charging stations.
Market Player/ Manufacturers	• Lead innovation in EV technology • Secure market share and global competitiveness • Ensure sustainable supply chains • Cooperate with charging operator for a robust charging infrastructure in order to increase their sales. • Creating different solution to meet EV users requirements.	• Supportive industrial policies • Access to raw materials • Stable demand signals from policy and consumer adoption • Reliable public and private charging options to increase rapid growth of EV adoption. • Increasing usage of EV for public and private transport as well as increasing charging points similar to gas stations. • Seeking standardized, user-friendly charging for cross brand EV compatibility. • Development and investments in DSO/TSO so they can adapt easily fast charging point.	• Invest in R&D for longer-range, safer, and cheaper EVs • Expand factories and supply chain integration • Collaborate with governments and utilities on standards • Adopt circular economy approaches (battery recycling, second life) • Deploying diverse chargers and plug types to meet varied EV and user needs. • Using smart charging systems with remote control, system integration, and AI optimization. • Providing charging solutions with vehicle ownership to ease range anxiety.
Market Player/ Services	• Grow value-added EV services ecosystem • Monetize data-driven mobility solutions. • Enhance user experience. • Creating frameworks and market rules to integrate EV flexibility and coordinate stakeholders effectively. • Helping tackle V2G technical challenges, ensuring standard protocols and interoperability between vehicles, chargers, and the grid. • Guiding businesses and grid operators on EV flexibility, helping them understand impacts and seize opportunities.	• Support for digital innovation and data-sharing policies • Stable platforms for service integration (payments, apps, V2G aggregation) • Offering detailed market data by size, OEM, region, and model. • Providing mid- and long-term EV market forecasts for strategic planning. • Examining trends like rising BEV adoption and the changing competitive landscape. • Assisting companies that focus internal combustion engines in adapting and innovating for the growing EV market.	• Provide subscription-based mobility and charging services • Integrate EVs into shared mobility platforms • Partner with fintech, insurance, and energy companies for bundled services • Assessing the feasibility and potential profits of EV projects and investments. • Assessing emerging EV technologies and charging infrastructure options. • Overseeing environmental assessments, permits, and licensing for EV projects. • Using real-time data to forecast costs, performance, and risks of e-mobility assets.

2.1.2 Agreement and disagreement points among key stakeholders

Overall, stakeholders have largely supported the development of the emerging EV ecosystem, with little evidence of active resistance from established industry players. Moreover, many stakeholders have expressed strong confidence in the future success of EVs, showing neither concern over immediate financial returns nor fear of long-term drawbacks. While their motivations for supporting EV development vary, a key unifying factor is the mounting regulatory pressure on the automotive sector, which increasingly compels traditional car manufacturers to produce electric or plug-in hybrid vehicles. This shift creates both opportunities and risks for stakeholders beyond the automotive industry, prompting them to engage proactively in EV and charging infrastructure initiatives. Their involvement often serves as a strategic move to better understand and navigate these potential changes. A particularly notable example is the active participation of local grid operators, among the most involved actors despite perceiving EVs more as a challenge than an opportunity. This highlights a broader insight that, stakeholders' participation in emerging niches is not driven solely by direct positive expectations of a new technology, but also by a need to anticipate and adapt to the transformations it may bring a perspective consistent with insights from socio/technical transition studies, [3].

2.1.3 Challenge of Developing Public Recharging Infrastructure

A key challenge in the early phase of the shift to electric mobility lies in determining how responsibilities should be divided between stakeholders (especially grid operators and electricity producers), [4]. These parties are eager to play a role in developing and managing parts of the public charging infrastructure. Grid operators (GO) advocate for taking an important role to ensure grid stability. GO argues that direct control over charging infrastructure would allow them to manage demand at the local level. In the short term, this approach helps avoid network overload, while in the long term it could reduce the need for costly grid reinforcements.

Electricity producers, on the other hand, envision a more market-driven approach. They propose building commercially operated charging networks that could be integrated into broader service packages such as home and workplace charging solutions offered to their customers. Under this model, the cost of infrastructure would largely fall on EV users rather than being covered by the general public through grid connection fees, as in the grid operators' plan. Furthermore, allowing each producer (or other service providers) to establish its own network could foster competition based on coverage and service quality, potentially driving faster development and lowering costs, similar to competition in mobile phone networks.

Despite these potential benefits, electricity producers remain cautious about investing in public charging infrastructure due to the absence of a clear, immediate business case. As a result, they are more likely to concentrate on private charging solutions and rely on public networks financed by local authorities.

2.1.4 Shaping Charging Habits

Both grid operators and electricity producers have strong incentives to implement controlled or managed charging within the EV ecosystem, but their priorities differ, [5]. At the macro level, electricity producers aim to maintain a balance between supply and demand, as sudden spikes in consumption can disrupt production schedules and increase costs. They also see managed charging to leverage EVs as energy storage buffers for integrating renewable energy sources. DSO's, on the other hand, focus on the micro level, seeking to prevent local overloads and ensure grid stability in specific areas. These interests often conflict for instance, producers benefit from charging as many EVs as possible during periods of surplus renewable energy, whereas simultaneous charging could overwhelm local distribution networks. a phenomenon grid operators strive to avoid.

This divergence underscores the need for careful planning and coordination. Currently, regulations give grid operators top-down control, in several countries, allowing them to manage who can charge and when. Regulatory frameworks vary significantly across Europe. Albania for instance, have fixed prices, and is strongly related to national/local factors, whereas in the Nordics, spot (hour to hour) prices are used to guide user decisions. In the future, regulatory adjustments may become commensurable across Europe and enable grid operators to influence charging behaviour indirectly through variable transport tariffs, while electricity producers might adopt dynamic kWh pricing to guide user decisions. Such pricing mechanisms are generally acceptable to other stakeholders, who believe financial incentives will effectively encourage users to adapt their charging patterns. Nevertheless, stakeholder's stress that EV drivers must always retain the option to charge when they need. Depending on context, restrictive, mandatory control measures as proposed by some grid operators, are widely viewed as unacceptable. For high-speed charging this can be a real problem, but for home charging, where the car is parked over many hours, less so.

2.1.5 Distribution of Public EVSE

Many current and prospective EV drivers (users) lack access to private charging facilities. Municipal approaches to public charging infrastructure, however, vary widely. Some cities approve nearly all requests for installing charging stations, while others are far more cautious, [6]. Policies also differ regarding the use of parking spaces next to chargers: in some cities, these spots are exclusively reserved for EVs, while in others, conventional vehicles are permitted to park there. Such inconsistencies are a major source of frustration for stakeholders. However, as battery technology and car range improve user behaviour can change making these spots less needed and used.

Generally, larger cities, driven by concerns about local air quality and high expectations for EV adoption, are more willing to approve public charging permits. However, these chargers often replace regular parking spaces, raising questions about how long this approach can be sustained. Smaller municipalities, where parking demand is lower, still show hesitation in allocating public charging spots, likely due to uncertainty about long-term effects. Establishing national guidelines for public charging allocation could help mitigate these challenges.

Ultimately, larger cities may need more strategic solutions, as growing EV numbers will require greater charging capacity, particularly overnight. Concentrating EV charging facilities in designated parking areas, rather than providing scattered semi-private chargers near individual homes, could improve charger utilization and reduce the overall impact on public parking spaces.

2.1.6 Establishing a Rapid-Charging Network

Most stakeholders acknowledge the importance of a nationwide fast-charging network for Ad-Hoc use. For example, in the Netherlands, this network is being developed by several companies that have been granted specific concessions to operate fast-charging stations along highways, [3]. The establishment of this separate concession system, alongside existing concessions for traditional fuel stations, has generated some controversy.

Operators of conventional fuel stations have objected, arguing that they should retain exclusive rights to operate fast-chargers as part of their existing fuel concessions. However, these concessions legally cover only traditional fuels, and electricity is not classified as a fuel, which necessitated the creation of a separate concession system.

Companies awarded the fast-charging concessions point out that oil companies were originally invited to install fast-chargers but showed no interest. Some respondents suggest that oil companies may be using this dispute to slow down the transition to electric mobility, while others believe the debate reflects broader dissatisfaction among oil companies with the existing concession framework, with the controversy serving as a form of protest. However, the behaviour of oil companies is strongly dependent on the national conditions and some areas experience a shift towards EVSE.

2.1.7 AC versus DC fast-charging

Stakeholders hold differing opinions regarding the preferred plug standard(s) for EV charging, flexibility of installation, cost for integration and installation, efficiency and speed of charging in AC/DC, peak power and other parameters related to EVSE. These preferences vary both between and within stakeholder groups, [2].

Automakers and consumers often favour AC charging for its compatibility with on board chargers and lower cost, while DC fast charging is preferred for long distance travels due to the reduced charging time. Another key point is the charging efficiency. Charging from DC power sources such solar system can significantly reduce losses. Charging operators and grid operators have a different perspective, they need to balance deployment costs and grid impact. DC offers a faster turnover and a more suitable integration with the solar and storage systems. Standards such as CCS2, CHAdeMO, and NACS play a critical role in shaping the adoption of electric vehicles by defining compatibility and ensuring interoperability across charging networks. These standards influence not only the physical connector design and communication protocols but also the efficiency, safety, and user accessibility of charging infrastructure, hence directly impacting market penetration and the seamless integration of EVs into existing power systems.

From an infrastructure standpoint, installing AC chargers with a power range 7 to 22 kW, is most practical. These chargers EVSE are relatively inexpensive and require modest grid connections. In contrast, car manufacturers favour DC   charging because it allows vehicles to be charged faster allowing a use similar to ICE (internal combustion engine) vehicles. In addition, AC necessitates on board AC/DC converters. About V2G DC charging, stakeholders have e general positive point of view. For example, EV owners favour it for financial benefits and flexible charging, while grid operators value it for stability, renewable integration, and peak load management. They all agree that the optimization and coordination of charging and discharging is important to maximize both owner revenue and grid stability/efficiency. Overall, V2G is seen as a win-win solution for all of stakeholders, if properly managed, [7].

2.2 Stakeholder Survey

This study also collected information directly from stakeholders through a questionnaire-based survey with the aim to identify the most effective indicators and the most important requirements that stakeholders have regarding the EVSE.

2.2.1 Scope of the Survey

The primary objective of this survey is to provide important insights that can inform and guide the development of comprehensive strategic plans, policies, and roadmaps for creating a reliable, scalable, and easily accessible EV charging infrastructure. It collects and analyse data on key factors such as current charging network coverage, charging speeds and technologies, user behaviour and preferences, grid capacity, investment requirements, and potential geographic gaps in service.

By offering a holistic understanding of these aspects, the survey facilitates the alignment of diverse stakeholder interests, including those of policies makers, utility providers, automotive manufacturers, charging point operators, and end users. This alignment is essential to ensure that infrastructure deployment is efficient, cost-effective, and sustainable. Moreover, the insights gathered help address challenges such as interoperability, standardization of charging protocols, integration of renewable energy sources, and the development of incentives to encourage private-sector participation.

Ultimately, the survey serves as a foundation for informed decision-making, enabling the implementation of EV charging solutions at the end-users that not only meet today's needs but are also adaptable to future technological advancements, market growth, and evolving consumer expectations.

2.2.2 Format and question of the survey

This survey is designed to provide a comprehensive understanding of user requirements related to EVSE and collects data from various stakeholders part of the AHEAD consortium. The first section collects information on the primary stakeholder category of the respondent, such as policymaker, infrastructure provider, energy company, end user, and equipment manufacturer, while section 2 and 3 collect several variables for each respondent, including needs, priorities, challenges, and expectations. This allows us to relate these variables to unique stakeholder categories. This section also addresses the geographic focus of the stakeholders' activities to understand if they are concentrated in a specific local area, cover a wider region, span the entire country, involve multiple European countries, or have a global reach.

Section 4 focuses on the respondents' individual experience as an EV driver, allowing them to highlight any personal needs, preferences, or interested points that may differ from the general perspective of EV user needs reported in the previous sections. By combining insights on stakeholder views and experiences, it is possible to identify common ground, address specific concerns, support the development of effectiveness, and improve EV charging solutions.

APPENDIX A presents the questionnaire that was distributed to stakeholders through all the partners of the AHEAD project.

2.2.3 Distribution link, method of distribution

The software SurveyXact were used to complete this survey which is a flexible and efficient platform for its distribution to the diverse group of EV stakeholders across Europe. The platform also allowed survey to be distributed through multiple channels, including direct email invitations, which were mainly used for this survey. Other options are personalized links for individual respondents, open links for broader accessibility, and QR codes for easy mobile participation.

SurveyXact enabled segmentation of these diverse groups, allowing for tailored survey invitations and follow-ups to ensure that each stakeholder type receives relevant questions. Automated reminders were scheduled twice to boost response rates, while real-time tracking provides insights into participation levels across different regions and stakeholder categories.

The survey was designed in English, which is a suitable language to reach stakeholders across multiple European countries. Combined with features for secure data collection and anonymization, SurveyXact ensured that responses are both reliable and representative. All data are anonymous and stored safely on a server at Roskilde University. Overall, the platform facilitates efficient, targeted, and comprehensive data collection, enabling European stakeholders to provide valuable information on EV infrastructure, policies, and user needs. One limitation of the survey is that the responders who decide to participate may be proactive why selection bias in any survey may be apparent. Further, the responders may be more risk taking as they have no direct responsibility over their choices made. This may affect the survey results.

2.2.4 Survey Results

The survey results are based on a sample of 113 responses. The survey had a response rate of 42%. Among the 113 respondents 14% did not complete the whole survey; hence the total number of respondents (N) may vary depending on the question. In the following we present the main results.

Stakeholder characteristics

Job type and organisation

All respondents are selected based on their capacity as an EV expert. The first part of the survey therefore seeks to establish expert status and capacity by asking questions regarding the respondents' job type and function, and the kind of company or organization they work for (questions 1 and 2). This information was also used to group the respondents into stakeholder types and to exclude potential non-experts from the survey (two respondent were excluded) (see Figure 2.2). The questions were open-ended to collect as much detail as possible.

Figure 1. We would first like to know some basic information about your organization / company and the kind of work you do there. Please briefly describe your role (job title) and function in the organization / company you work for.

“Regional Director for company XXXXXXX which focuses on charging infrastructure. In this role, I am responsible for overseeing the company’s operations and business development within the region of mainland Europe, leveraging prior professional experience to lead strategic initiatives and regional growth for XXXXXX”

“We are a software provider, empowering businesses to create their own EV charging ecosystem. Our primary focus is Charging-as-a-Service (CaaS), enabling seamless integration into your company’s branding and operations. We provide a cloud-based platform for managing charging stations, designed for both Charge Point Operators (CPOs) and eMobility Service Providers (eMSPs).”

“I am a chief analyst, one of two people in Danish e-Mobility. Working with everything related to charging EVs in an Industry organization. Statistics regarding number of chargers, taxes and regulation regarding chargers/electricity, EU-regulation etc.”

“Job title: Electrical Engineer. Role: Charge Point Infrastructure integrations. Working with everything charging hardware, OCPP, IEC 61851 and ISO 15118. And all the stuff in between like load management and grid services.”

Figure 2. Please write the name of your organization / company. If you do not want to state the name, please briefly state its main area(s) of activity or business.

Figure 2.2: Questions on stakeholder characteristics.

Stakeholder type

Question 3 concerns stakeholder types (Figure 2.3). Thirty-three percent of the interviewed stakeholders are IT developers, with EV associations being the second largest stakeholder group at 10%, followed by service providers (8%) and TSOs (6%). None were policy makers. Twenty percent of the respondents did not believe that they belonged to any of the pre-coded categories and unfortunately the survey format did not allow these to specify their category as free text.

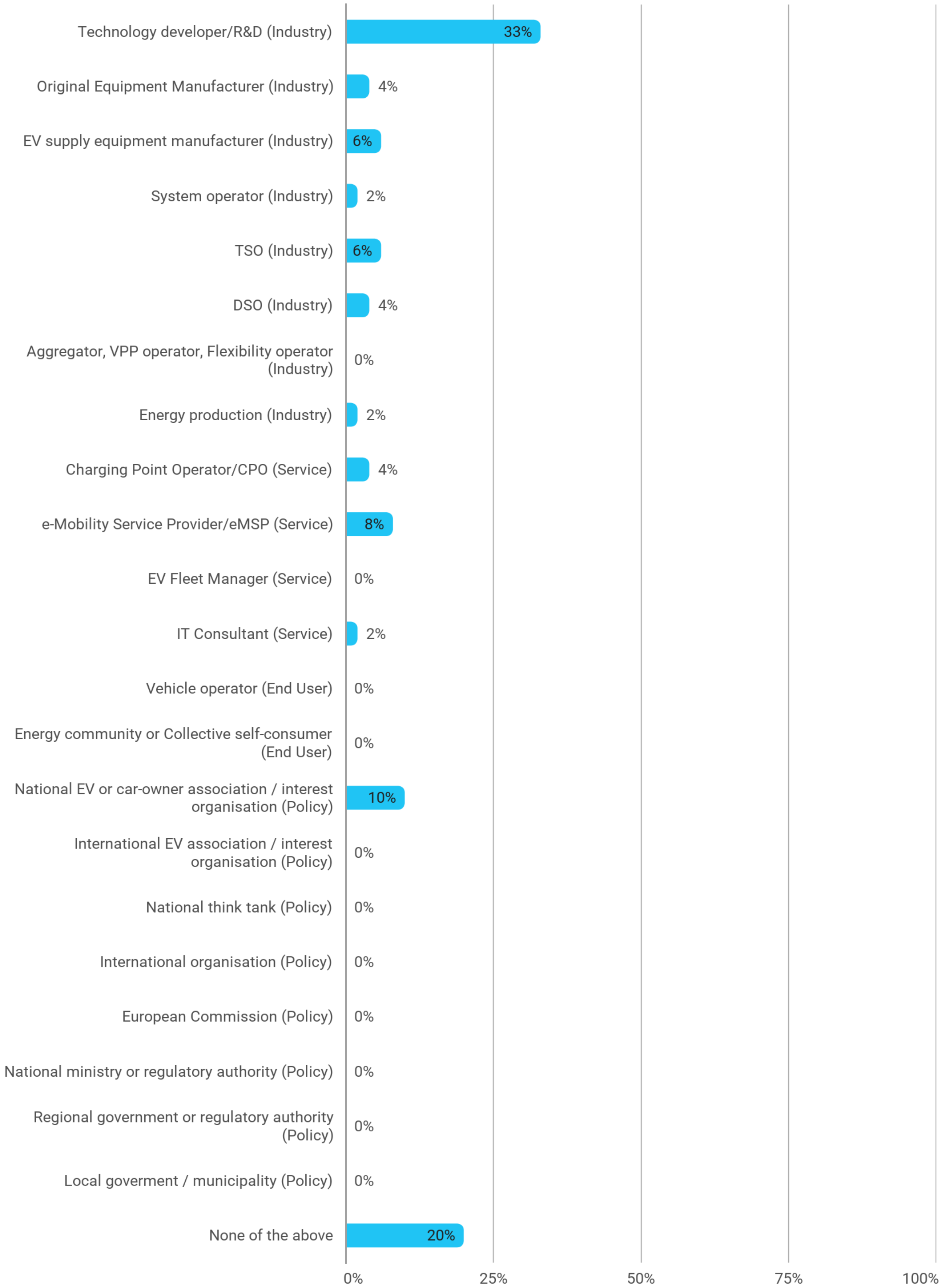


Figure 2.3: Please select below the stakeholder type that best represents your company / organisation (select one or more options) (N=113).

Geographical scope of stakeholders' activities

To enable geographical analysis, stakeholders were asked about their geographical focus, i.e., whether their operating area was primarily local, national or international (Figure 2.4). The respondents primarily have an international or European focus (52%), then national (26%), with regional or local orientation being less common (22%). This pattern may be explained by the fact that most of the respondents are technology developers.

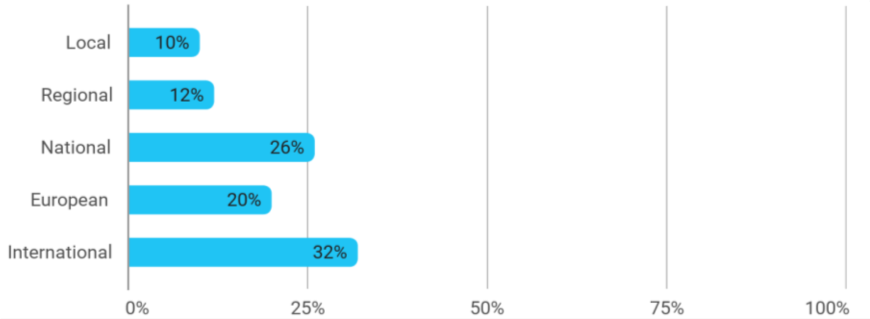


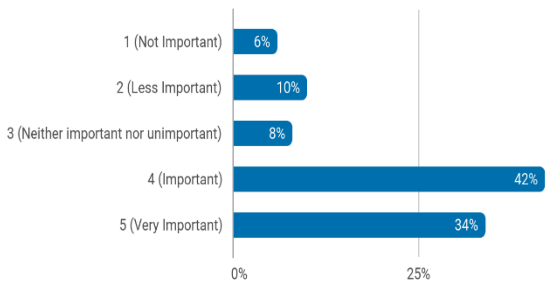
Figure 2.4: What is the geographic focus of your company/organisation's activities? (N=113).

Charging infrastructure, coverage and accessibility

The survey's second section concerns Key Performance Indicators (KPIs) grouped into 5 themes (reference figures). The KPIs are measured on a likert scale, ranging from 1 (Not Important) to 5 (Very Important). Finally, the respondents are asked to prioritize the themes. The KPI results are presented in turn below.

The first theme (Figure 2.5) concerns charging infrastructure, coverage and accessibility. Geographical coverage concerns the location of EV chargers to facilitate accessibility, hence a KPI of coverage geographically. According to the respondents (Figure 2.5.a), geographical coverage is important to facilitate a high service standard as 65% of them find it important or very important.

a) How important is it to ensure broad geographic coverage? (N=113)



b) Hov important is it to ensure accessibility in rural/underserved areas? (N=113).

c) How important is real-time information on station availability? (N=112).

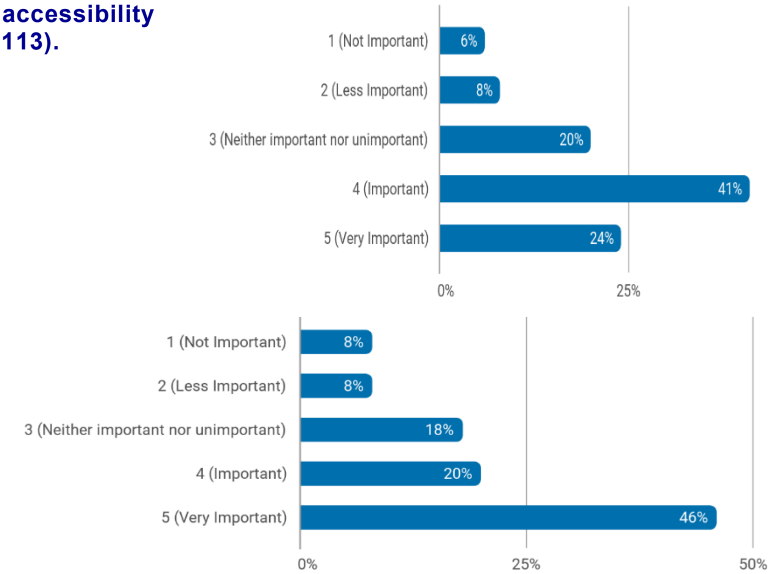


Figure 2.5: Charging infrastructure, coverage and accessibility.

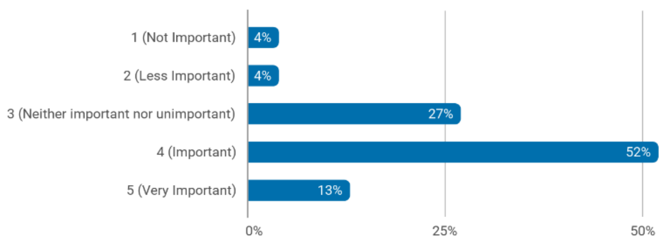
The same tendency can be seen from Figure 2.5.b, according to which 65% of the respondents find it important or very important to ensure accessibility also in rural/underserved areas, even though they often have a lower investment return ratio (se also Figure 2.7.b).

Finally, we asked about the convenience of getting real-time information on station availability. This question addresses a KPI by evaluating the respondent's view of end-user's service needs (Figure 2.5.c). Real time information is considered crucially important, as 46% find it very important and 20% find it important to the end-users.

Charging Speed & Reliability

Section 2.B of the survey concerns charging speed and reliability, two important KPIs according to the review (Figure 2.6). First the respondents are asked about the availability of fast charging stations (Figure 2.6.a). Thirteen percent find charging speed to be very important and but the given that 52% find charging speed important, it is indicating a strong preference for this attribute of the charging infrastructure, but furthering ultra-fast changing seem to slightly drop as a priority as 13% find it very important. This may be due to the fact that ultra-fast charging affects a battery's life cycle, but also that ultra fast charging is usually located in clusters at nodal points etc, where additional services are important.

a) How important is the availability of fast/ultra-fast chargers (N=109).



b) How important is minimal downtime and high operational reliability? (N=109).

c) How important is short waiting times at charging stations? (N=109).

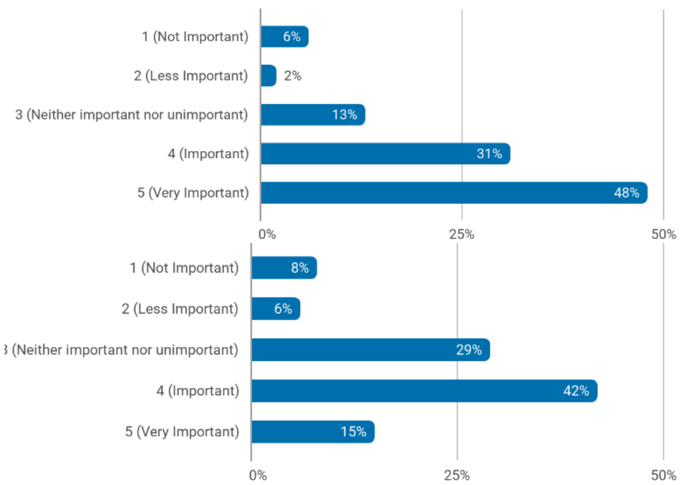


Figure 2.6: Charging Speed & Reliability

The reliability of charging infrastructure, measured here as minimum downtime and high operational reliability, is a very important KPI according to the respondents' understanding of end users' service needs. Figure 2.6.b shows that 79% of respondents find minimum downtime and operational reliability either important (31%) or very important (48%), indicating that stakeholders perceive operational failures to have a significant impact on end-user experiences.

Similarly, the responders were asked to assess the extent to which they find short waiting time important (Figure 2.6.c); 15% and 42% found this KPI to be very important and important, respectively, while 29% found it to be neither important nor unimportant, suggesting a fairly strong preference for this attribute of the charging infrastructure. As waiting time is also influenced by charging speed, it is not surprising that the importance attributed to these two KPIs are similarly large.

Economic & Market Conditions

Section 2.C of the survey evaluates the respondents' understanding of economy and market conditions in the EV sector (Figure 2.7). As seen from Figure 2.7.a, affordable charging for end users is a significant economic factor, with 77% of the respondents finding it either important or very important.

The importance assigned to variables affecting the profitability of charging-infrastructure operators (utilization rates and return on investment) are comparable to those directly affecting users, with 69% of respondents finding these economic aspects either important or very important (Figure 2.7.b).

a) How important is affordability of charging for users? (N=104)

b) How important is high utilization and return on investment (ROI) for operators?

c) How important is fair and transparent pricing models? (N=104)

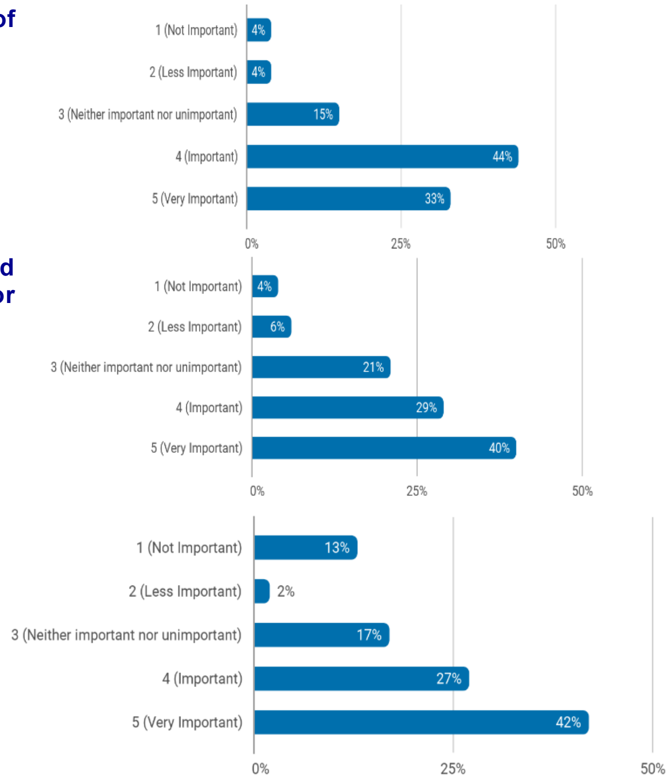


Figure 2.7: Economic and Market Conditions

Another factor affecting the charging economics of EV users is fair and transparent price models (Figure 2.7.c). Respondents found this attribute slightly less important than affordable charging (even if the two attributes are closely related), with 27% and 42% (69% in total) deeming it important and very important, respectively. (Stakeholders' perception of price elasticity was not assessed.)

Renewables and Grid Integration

Respondents also assessed the importance of aspects of the broader energy system that the charging infrastructure forms part of, i.e. the use of renewables and grid integration (grid stability and peak demand management), the latter of which is a key concern of DSOs and TSOs. Here, 66% found renewable energy use important or very important (Figure 2.8.a), while an even larger share of respondents (81%) believed that grid stability and peak demand management were important or very important (Figure 2.8.b).

Smart (flexible) charging and V2G charging can benefit both grid stability (including peak demand management) as well as facilitate a greater use of renewables in e-mobility systems, so stakeholders were also asked to assess these variables. It is noteworthy that 77% of stakeholders found support to smart (flexible) charging either important or very important

(Figure 2.8.c), while for V2G charging the same was true for only 54% of the respondents (Figure 2.8.d).

a) How important is the use of renewable energy for charging?

b) How important is grid stability and peak demand management? (N=104)

c) How important is support for smart (flexible) charging? (N=103)

d) How important is support for vehicle-to-grid (V2G) charging? (N=103).

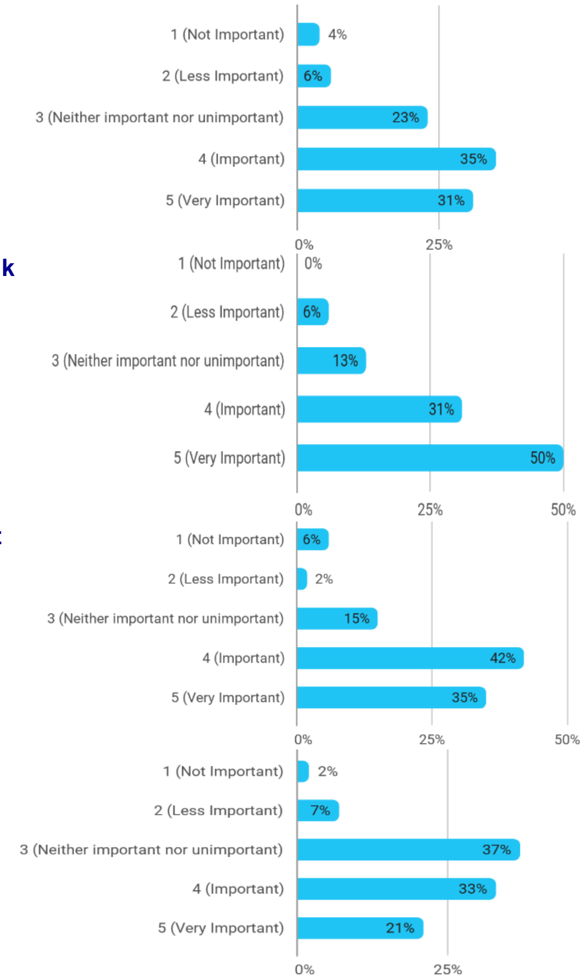
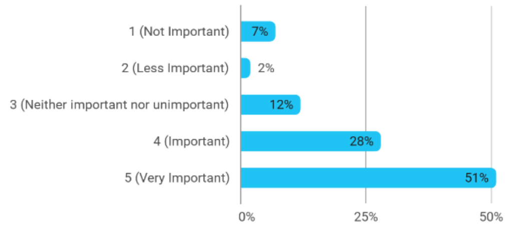


Figure 2.8: Renewable Energy Use and Grid Integration

User Experience & Satisfaction

This section deals with how the interviewed experts perceive the preferences of end users (consumers or costumers) for different attributes of charging infrastructures (Figure 2.9). The first attribute concerns the ease-of-use of customer-facing services or technologies, especially apps, payment models, and general user interfaces. Unsurprisingly, experts attach great importance to customers' ease-of-use, with 51% finding it very important and 28% important (Figure 2.9.a). Much fewer respondents find that the availability of station amenities is very important (5%) or important (30%) for end users (Figure 2.9.b). The latter finding is surprising and contrasts with other surveys, from e.g. Norway (The Norwegian Electric Vehicle Association, personal communication). A reason for this discrepancy may be the fact that the responders are experts, not the end users. Another explanation may be the present survey's use of the unspecific term 'station amenities and lack of contextual information regarding on aspects such as location (workplace, highway, etc.) and type of charger (slow or fast).

a) How important is the ease of use for customers (of apps, payment, user interface)? (N=103)



b) How important is the availability of station amenities? (N=101).

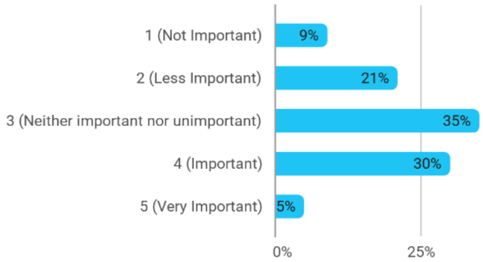
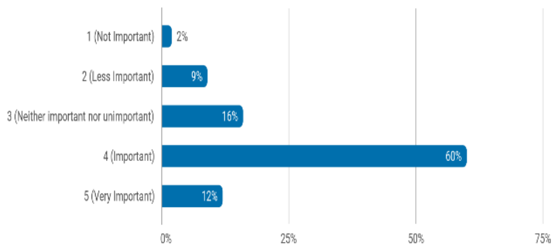


Figure 2.9: User Experience and Satisfaction

Technology Innovation & Standardization

This section delves into the expert's expectation to future technology and standardization needs. Respondents measure the importance of technology innovation highly and 60% find technology innovation important and 12% highly important (Figure 2.10.a). Standardization, however, score even higher, as 42% find standardization important and 53% very important (Figure 2.10.b). This indicate there is standardization needs in the market. As 95% of the respondent's rate standardization of importance, this indicate there such be looked further into regulatory and standardization needs, as well as more research into possible standardization gaps.

a) How important is technology innovation?



b) How important is technology standardization?

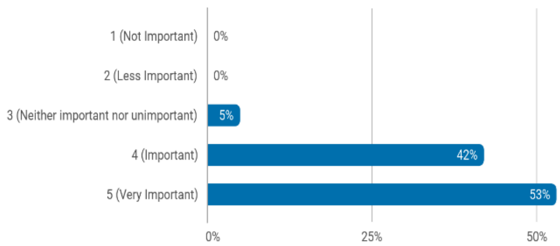
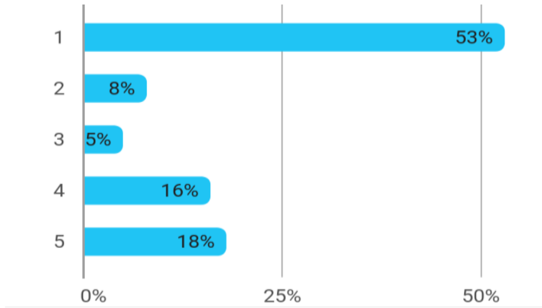


Figure 2.10: Technology and standardization

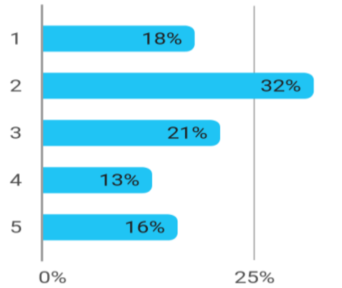
Top priorities – rating different KPIs

The final part of the survey asked respondents to prioritize the different KPI against one another. Asked to consider the most important properties or functionalities as a driver (actual or potential) of an electric vehicle. The respondents prioritized and rated the following topics, each in turn: Charging Infrastructure Coverage & Accessibility (Figure 2.11.a), Charging Speed & Reliability (Figure 2.11.b), Economic and Market Conditions (Figure 2.11.c), Grid Integration (Figure 2.11.d). Figure 2.11.a shows that *charging coverage and accessibility* is given highest priority with 53% assigning the topic top priority and 18% rating the topic second highest. *Charging Speed & Reliability* receive the second highest score. 18% of the respondents prioritize charging speed and reliability as the priority, 32% as the second (Figure 2.11.b). By contrast, both *Economic and Market Conditions* (Figure 2.11.c) and *grid integration* (Figure 2.11.d) have 8% of the responder's top priority each. According to the survey data, grid integration appears as the least important topic to EV drivers. Thus, 32% prioritize grid integration as the fourth most important topic. 34%, find grid integration less important and 5 give the theme the lowest priority. Consequently, EV drivers seem to prioritize grid integration the lowest, hence renewable energy charging, according to the experts in this survey. It should be noted, however that EV drivers have not been specifically asked into renewable energy.

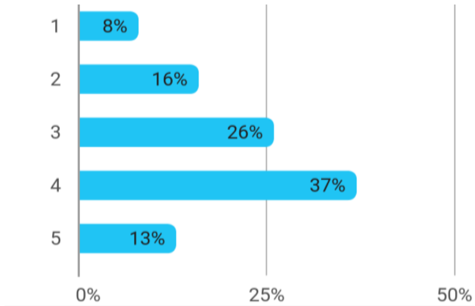
a) Charging Infrastructure Coverage & Accessibility - What is your priority from the list below?



b) Charging Speed & Reliability - What is your priority from the list below? (N=98)



c) Economic and Market Conditions - What is your priority from the list below? (N=98).



d) Grid Integration - What is your priority from the list below? (N=98)

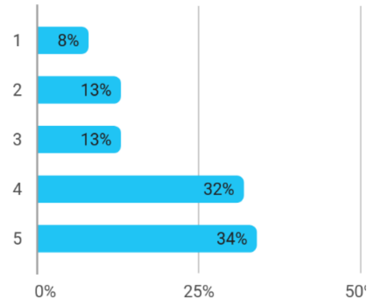


Figure 2.11: Prioritization of KPI.

2.3 Requirements and Objectives

This section provides detailed requirements and objectives for EV integration, drawn from the analysis of the literature and the survey results. The insights are grouped into thematic areas to provide a coherent understanding of the strategic, technical, financial, environmental, stakeholder, and innovation-related dimensions necessary for successful EV integration.

2.3.1 Policy and Regulatory Frameworks

To ensure the long-term success of EV adoption, national and regional authorities must set clear targets for deployment that align with broader decarbonization and climate strategies. These targets provide direction for infrastructure investment, stimulate market confidence, and ensure that progress is measurable over time.

- Regulatory measures should govern the deployment of charging infrastructure, covering aspects such as strategic site selection, adherence to safety standards. For ensuring interoperability, internationally recognised open communication standards and protocols, namely IEC 63584 (OCPP), OCPI, OSCP and ISO 15118 should be endorsed. This ensures that users can access charging facilities easily and that investments are future proof.
- Electricity market rules need to evolve to enable and encourage V2G services. Governments should establish a remuneration scheme and facilitate easier access to electricity markets for demand side flexibility providers. By incentivizing flexible demand, EVs can play a pivotal role in balancing grid loads, supporting renewable integration, and reducing reliance on fossil fuels. Robust data governance frameworks must be established to regulate the collection, sharing, and use of charging and energy consumption data. These frameworks are crucial for protecting consumer privacy while enabling data-driven innovation in the EV sector. EU's new Battery Regulation mandates the Digital Battery Passport, and is an example of data governance which monitor about battery health etc. Battery data will be essential if we are going to use EVs for V2G.
- Double taxation of the bidirectional charging of EVs should be prevented as a financial incentive.

2.3.2 Technical Infrastructure Requirements

A well-developed charging network is essential for mass EV adoption. This network should be built on standardized connectors, harmonized payment systems, and unified communication protocols, ensuring that users enjoy a seamless charging experience regardless of location or service provider.

- The integration of EVs will create additional stress on electricity grids, particularly in high-demand areas. Grid reinforcement, combined with the deployment of smart charging systems, will help manage load profiles and prevent infrastructure overload.
- Interoperability between charging stations and energy management systems is critical for unlocking the potential of V2G services. This ensures that EVs can serve as distributed energy resources, feeding electricity back into the grid when needed. This should consider all stakeholders as V2G services have an impact on the battery state of health and should operate within the manufacturer limits.
- Predictive maintenance and remote monitoring technologies should be implemented for charging infrastructure. This enhances system reliability, reduces downtime, and optimizes operational efficiency.

2.3.3 Economic and Financial Objectives

The upfront costs of charging infrastructure deployment can be significant. Public and private funding mechanisms must be designed to support both the initial investment phase and ongoing operational costs, ensuring long-term sustainability.

- Targeted subsidies, grants, or tax incentives should be introduced to accelerate EV adoption among consumers and commercial fleets. Such financial measures can help bridge the cost gap between EVs and conventional vehicles.
- Innovative business models are necessary to encourage private sector participation in public charging infrastructure provision. Revenue-sharing agreements, concession models, and joint ventures can make such investments more attractive.
- Ensuring equitable access to charging facilities is a core objective. Policies should address urban–rural disparities, making sure that all communities benefit from EV adoption regardless of geographic location.

2.3.4 Environmental and Social Goals

The transition to electric mobility is a critical strategy for reducing greenhouse gas emissions from the transportation sector. Achieving high levels of EV penetration will significantly contribute to meeting national and international climate commitments.

- Widespread EV adoption will improve air quality in urban areas, leading to measurable public health benefits. Reduced vehicle emissions will also lower exposure to harmful pollutants, especially in densely populated regions.

- EV integration should be complemented by a broader modal shift toward sustainable transport modes such as public transit, cycling, and walking. This holistic approach maximizes environmental benefits and reduces congestion.
- Equity must remain at the heart of EV policy. Special attention should be given to ensuring that low-income, remote, and underserved communities have access to affordable EV options and charging facilities.

2.3.5 Stakeholder Engagement and Governance

A successful EV ecosystem depends on collaboration among diverse stakeholders, including utilities, vehicle manufacturers, municipalities, and consumer advocacy groups. Structured platforms for dialogue and coordination are essential to align objectives and avoid duplication of efforts.

- Clearly defining the roles and responsibilities of each stakeholder group ensures accountability and smooth project execution. Role clarity also helps prevent conflicts and overlaps in infrastructure planning and service delivery.
- Demonstration projects and pilot programs serve as effective tools for testing new technologies, business models, and regulatory approaches. Sharing best practices from these initiatives accelerates learning and replication across regions.
- Transparent governance mechanisms should be in place to address potential conflicts of interest and maintain public trust. These mechanisms promote fairness and inclusivity in decision-making.

2.3.6 Research, Development, and Innovation

Continuous advancements in battery technology are essential for improving energy density, battery life, recyclability, and vehicle range, while reducing manufacturing costs. These innovations directly impact EV affordability and environmental performance.

- V2G technology must be further developed to provide valuable grid services while maximizing the benefits of renewable energy integration. This will require advancements in both hardware and software solutions.
- The development of cutting-edge charging technologies, such as wireless charging and ultra-fast stations, will further reduce charging times and improve convenience for users. These solutions can also support heavy-duty and commercial EV segments.
- Data analytics, artificial intelligence, and digital twin technologies can be leveraged to optimize EV fleet operations, forecast energy demand, and guide strategic infrastructure investments.

2.4 Stakeholder classification

2.4.1 Introduction

Stakeholder classification is a foundational element in the strategic planning of electric vehicle (EV) infrastructure, ensuring that every actor's role, responsibility, and influence is clearly understood and coordinated. This document presents a comprehensive analysis based on a synthesized review of academic studies, real-world demonstration projects, and a categorized stakeholder table. The classification is based on shared goals, expected outcomes, and their roles within the EV ecosystem. We examine why this classification is necessary, how it relates to overarching policy and energy goals, and what indicators reflect the performance of each stakeholder group.

2.4.2 Rationale Behind Stakeholder Classification

Stakeholders are classified based on their functional role in the EV ecosystem: regulatory, operational, technical, or social. This method aligns with both academic frameworks and policy models such as the WBCSD Value Framework and various European EV integration projects. Grouping stakeholders allows for targeted policies, efficient communication, and effective management of project responsibilities.

2.4.3 Objectives of Stakeholder Engagement

The classification helps clarify the objectives of each stakeholder. For example, municipalities aim for sustainable urban mobility, while grid operators seek load balance and grid stability. Research institutions provide data-driven insights, and industry players focus on technological deployment and service profitability. These differing but complementary objectives require harmonization to avoid conflicts and ensure systemic success.

2.4.4 Indicators of Stakeholder Performance

Each stakeholder group can be evaluated by specific indicators. These include adoption rates, infrastructure density, user satisfaction, grid performance metrics, and policy compliance. The integration of these indicators allows stakeholders to track their contributions and improve decision-making over time.

2.4.5 Classification

The following table presents a structured classification of key stakeholders within the electric vehicle (EV) ecosystem. It groups stakeholders based on their functional roles, provides concise descriptions of their involvement, outlines their primary objectives, and identifies relevant result indicators. This classification supports strategic planning, coordination, and performance evaluation across technical, policy, economic, and social dimensions.

This classification approach is validated by a comprehensive review of demonstration projects and stakeholder mapping literature, showing that the complexity of the EV transition requires a systemic and integrated stakeholder framework.

The stakeholder table consolidates the entities involved in the deployment, regulation, and usage of Charging Infrastructure (CI), offering a structured categorization into institutional groups, Table 2. These groups include public authorities (municipalities and regulators), knowledge institutions (research and education), societal advocates (consumer associations, environmental organizations), infrastructure operators (DSOs, TSOs), and industry actors (OEMs, service providers, GENCOs). This classification is not based on their identity but rather on their function within the EV ecosystem. Each group brings specific objectives: regulatory consistency, sustainable technology deployment, public acceptance, grid stability, or financial return. Their interplay is crucial for the successful integration of CI in urban and regional planning. Therefore, this table is not merely descriptive but conceptual, illustrating how diverse stakeholder objectives align or diverge, and how governance strategies must be multi-actor and multi-scalar. These stakeholders were selected because they directly influence EVSE planning, operation, or regulation within the project pilots.

Table 2: EVSE Stakeholders

ID	Name	Description	Objective	Result indicators	Group
	Name of the stakeholder	*Description of the activities of the stakeholder*	*Objectives that the stakeholder wants to achieve*	*Indicators that quantify the results*	
1	Municipality	Facilitate road transportation in cities	Achieve sustainability goals in a cost-effective way	Air quality improvements due to CI Climate change improvements due to CI Achieved cost effectiveness of CI	Policy Makers
2	Research, Education	Gives advice to other stakeholders	Train other stakeholders needed for development of EVSE infrastructure.	Quantitative research results such as EV adoption rates, environmental benefits, and grid stability.	Policy Makers
3	Environmental Organisation	Promotes policies that support clean transportation and EV charging infrastructure.	They support building EV charging stations in a way that is safe for nature and communities. Ensuring electric vehicles are powered by renewable energy sources such as solar or wind.	Reduce air pollution and greenhouse gas emissions.	Policy Makers
4	Consumer Organisations (EV Associations, Driver Advocacy Groups)	Non-governmental organizations and associations that represent EV drivers' interests by advocating for consumer rights, equitable access, and improved charging services.	Ensure that the voices of EV users are integrated into policy decisions and that charging infrastructure is reliable, accessible, and user focused.	Formal inclusion in policy advisory bodies. Measurable improvements in consumer satisfaction and equitable charging access. Documented policy changes driven by consumer advocacy.	Policy Makers
5	Regulators	Government bodies and regulatory agencies at national, regional, and supranational (e.g., EU) levels responsible for developing, coordinating, and enforcing policies, standards, and support measures for electric mobility. This includes those setting the National Policy Frameworks (NPFs), directives (such as the AFI Directive), and other legislative instruments that shape infrastructure deployment and BEV uptake.	To create a harmonized and enabling policy environment that supports the expansion of recharging infrastructure, ensures interoperability across borders, and removes barriers to electric passenger car uptake. Their aim is to establish clear targets and effective support measures that drive market growth while avoiding over- or under-investment.	Adoption and implementation of coherent and harmonized national and EU policies and regulatory frameworks. Achievement of recharging infrastructure sufficiency indices. Documented increases in BEV market penetration linked to policy interventions and support measures. Measurable improvements in cross-border interoperability and the standardization of recharging infrastructure.	Policy Makers

6	Public Transport Operators	Organizations responsible for operating public transit services such as trains, buses, or metros. They are key in transitioning public transport fleets to zero-emission systems and integrating charging infrastructure that supports these operations.	Ensure a smooth transition to zero-emission public transit by incorporating efficient, accessible charging infrastructure that supports fleet electrification and seamless integration with urban mobility systems.	A higher proportion of electric vehicles in public transit fleets. Measurable reductions in operational CO_2 emissions. Improved service reliability and passenger satisfaction. Successful integration of charging infrastructure with transit hubs	Public Utility
7	Road managers	Public entities managing roads and traffic	Achieve cheap and safe road transportation while ensuring customer satisfaction and alternative paths		Public Utility
8	Grid operators	TSO/DSO	Safeguard grid quality	Risks of power outage / grid-congestion reduced. Smart charging options facilitated.	Grid Operators
9	Generation Companies (GENCOs)	Organizations that own and operate power generation assets. They are responsible for producing electricity and are key players in electricity markets. With the integration of EVs—especially through V2G concepts—GENCOs face new opportunities and challenges, as EVs can supply ancillary services and influence generation dispatch.	To optimize power production and system balancing by adjusting generation schedules and leveraging EV-based ancillary services. They aim to improve system efficiency, reduce peak load impacts, and participate competitively in energy and reserve markets as EVs provide additional flexibility.	Changes in generation dispatch patterns and peak load reduction. Increased revenue or cost savings from ancillary services provided by EVs. Improved overall system reliability and reduced need for expensive peaking generation. Documented participation in market mechanisms that incorporate V2G services.	Grid Operators
10	EV users or candidates	Companies or individuals that own or may own an electric vehicle	Stimulate electric mobility by enabling charging	Increased Accessibility of CI Growth in number of users of CI	Users
11	Residents (non EV-users)	Other non-electric car users	Optimize utilization of CI and manage parking pressure	Increased level of utilization of CI	Users
12	Flexibility Aggregators (Virtual Aggregators)	Entities that develop and implement smart control platforms to coordinate the charging and discharging of EVs—aggregating distributed flexible capacity—to provide ancillary grid services. These organizations leverage	Optimize grid stability and cost-effectiveness by harnessing the aggregated flexibility of EV charging. Their aim is to provide services such as frequency regulation, load balancing, and demand response while ensuring	Demonstrated improvements in grid frequency response and load balancing in field tests. Quantifiable revenue from ancillary services (e.g., profit per EV from frequency control, as highlighted in the	Market Player/ Operators

		data, real-time algorithms, and communication protocols (e.g. virtual aggregators in projects like ACDC) to enable EVs to act as dynamic storage assets.	that battery degradation remains minimal and user requirements are met.	ACES project). Verified technical performance of bidirectional control systems (e.g., response time and power modulation metrics). Validated economic benefits and minimal additional battery degradation through pilot deployments.	
13	Local Flexibility Market Operators	Entities that design, implement, and manage the local flexibility market platform. They act as intermediaries between distribution system operators (DSOs) and aggregators, coordinating auctions, bid submissions, and market clearings for flexibility services.	To enable DSOs to procure reliable and economically viable flexibility services well in advance, supporting network planning and congestion management by ensuring transparent, efficient, and fair market operations.	Market participation and bid submission rates by aggregators. Improved accuracy in flexibility procurement. Measurable economic benefits from avoided grid reinforcement costs. Documented improvements in DSO service activation and network performance.	Market Player/ Operators
14	Market Operators (Local Flexibility Market Operators – Independent Role)	Independent entities responsible for managing and clearing the local flexibility market. They act as intermediaries between distribution system operators (DSOs) and aggregators by collecting flexibility service requests, running auctions, and coordinating bid evaluations—without disclosing sensitive information like the DSO's willingness to pay.	To facilitate a transparent, efficient, and fair market for flexibility services that enables DSOs to procure services for congestion management and grid reinforcement deferral. This role ensures that flexibility from distributed resources is reliably and economically integrated into grid planning.	Successful clearing of flexibility service auctions (e.g., high participation rates and effective bid matching). Measurable reduction in grid operational costs and congestion (e.g., reduced transformer overload events). Documented improvements in the economic benefits of flexibility services, such as quantified savings in avoided grid reinforcement investments. Positive feedback from DSOs and aggregators regarding market performance and service reliability.	Market Player/ Operators
15	Charging Site Operator (CSO)	Companies that manage the charging infrastructure (charging points) and the services related to it	Facilitate a positive business case	CI-costs reduced CI-benefits increased Business case CI improved	Market Player/ Operators
16	CPOs	Sell the actual energy to the EV driver and are responsible for the day-to-day operation of charging stations.	Ensuring efficient charging services for EV users.	Maximize usage of charging infrastructure (average % of time chargers are in use). Achieve profitability (Amount of money	Market Player/ Operators

				earned from per charging session or per kWh delivered)	
17	Commercial Vehicle Operators	Organizations and fleet operators managing commercial vehicles (including battery electric trucks and heavy-duty vehicles) that require specialized charging solutions to support efficient, cost-effective logistics and freight operations.	Facilitate the transition to zero-emission commercial transport by deploying tailored charging infrastructure that addresses the unique operational and economic needs of commercial fleets.	Increased installation of dedicated commercial charging hubs or depot chargers. Reduced vehicle downtime and improved operational efficiency. Measurable cost savings and environmental performance improvements in fleet operations.	Users
18	Charging Point Manufacturer	Manufacturers of EVSE.	Ensure EVSEs are safe and meet international standards.	Total EVSEsold Growth rate in sales compared to previous periods	Market Player/ Manufacturers
19	Car Manufacturer	Car manufacturers develop their charging network of cooperate with charging point operators to ensure that the charging infrastructure is sufficient for the driver.	Increase battery efficiency and driving range to meet consumer expectations. Develop fast-charging technology to make EVs more convenient.	Growth in electric vehicle sales due to wider availability of charging stations	Market Player/ Manufacturers
20	Consultancy	Gives advice to other stakeholders	Makes informed decisions on where and how to install EV chargers.	Success rate of deployments (X% of recommended projects being completed on time and within budget).	Market Player/ Services
21	Service Provider	Provide access to the large number of different charging point operator and they provide billing services to the drivers.	Ensuring charging stations are available, working, and easy to locate.	Increased availability of charging stations for users, leading to better convenience and reliability.	Market Player/ Services
22	Financial Institution	Provides loans or project financing for EV charging station deployment.	The objective is to make a profit by providing loans or financing to EV charging projects that are expected to grow and generate income.	Earn revenue from interest payments on loans provided for EV charging infrastructure projects.	Market Player/ Services
23	Real Estate (Owners/Managers)	Entities that own and manage commercial, residential, or mixed-use properties. They play a role in integrating EV charging infrastructure within urban spaces, optimizing space usage.	Leverage the deployment of sustainable charging infrastructure to increase property value, attract new tenants or users, and support energy efficiency and renewable energy integration.	Increased property values; higher occupancy or foot traffic around charging-enabled sites.	Market Player/ Services

2.4.6 Detailed Stakeholder Description

Based on the literature review, this section describes the stakeholders listed in Table 2, providing detailed explanations of their classification, role, objectives, and expected outcomes.

Municipality

Classified as part of 'Policy Makers', Municipality has the responsibility of facilitate road transportation in cities. Their efforts are guided by the objective 'Achieve sustainability goals in a cost-effective way', with results measured through.

- Air quality improvements due to CI
- Climate change improvements due to CI
- Achieved cost effectiveness of CI.

Research/Education

Within the electric vehicle ecosystem, Research/Education is recognized under 'Policy Makers'. Their function can be described is to advise other stakeholders, while they pursue the objective 'Train other stakeholders needed for development of EVSE infrastructure'. Progress is monitored by quantitative research indicators results such as EV adoption rates, environmental benefits, and grid stability.

Environmental Organisation

Operating in the category 'Policy Makers', Environmental Organisations undertake the task of Promotes policies that support clean transportation and EV charging infrastructure. Their stated objective is 'They support building EV charging stations in a way that is safe for nature and communities. Ensuring electric vehicles are powered by renewable energy sources such as solar and wind, and their performance is gauged by the reduction of air pollution and greenhouse gas emissions.

Consumer Organisations (EV Associations/Driver Advocacy Groups)

Identified under 'Policy Makers', the Consumer Organisations (EV Associations/Driver Advocacy Groups) contributes through Non-governmental organizations and associations that represent EV drivers interests by advocating for consumer rights, equitable access, and improved charging services. Their strategic purpose, 'Ensure that the voices of EV users are integrated into policy decisions and that charging infrastructure is reliable, accessible, and user-focused', is evaluated against result indicators like:

- Formal inclusion in policy advisory bodies.

- Measurable improvements in consumer satisfaction and charging access.
- Documented policy changes driven by consumer advocacy.

Policy Makers / Regulators

The role of Policy Makers / Regulators falls within the 'Policy Makers' group. They are primarily involved in Government bodies and regulatory agencies at national, regional, and supranational (e.g., EU) levels responsible for developing, coordinating, and enforcing policies, standards, and support measures for electric mobility. This includes those setting the National Policy Frameworks (NPFs), directives (such as the AFIR Regulation), and other legislative instruments that shape infrastructure deployment and BEV uptake. Their goal, 'To create a harmonized and enabling policy environment that supports the expansion of recharging infrastructure, ensures interoperability across borders, and removes barriers to electric passenger car uptake. Their aim is to establish clear targets and effective support measures that drive market growth while avoiding over- or under-investment', shows their influence in the EV sector, and their effectiveness is reflected in indicators like:

- Adoption and implementation of coherent and harmonized national and EU-level policies and regulatory frameworks.
- Achievement of recharging infrastructure sufficiency indices (e.g., meeting or exceeding the recommended PEV-to-RP ratios).
- Documented increases in BEV market penetration linked to policy interventions and support measures.
- Measurable improvements in cross-border interoperability and the standardization of recharging infrastructure.

Public Transport Operators

Classified as part of 'Public Utility', Public Transport Operators has the responsibility of Organizations responsible for operating public transit services such as trains, buses, or metros. They are key in transitioning public transport fleets to zero-emission systems and integrating charging infrastructure that supports these operations. Their efforts are guided by the objective 'Ensure a smooth transition to zero-emission public transit by incorporating efficient, accessible charging infrastructure that supports fleet electrification and seamless integration with urban mobility systems', with results measured through:

- A higher proportion of electric vehicles in public transit fleets.
- Measurable reductions in operational CO_2 emissions.
- Improved service reliability and passenger satisfaction.

- Successful integration of charging infrastructure with transit hubs.

Road managers

Within the electric vehicle ecosystem, Road managers are recognized under 'Public Utility'. Their function can be described as public entities managing roads and traffic, while they pursue the objective 'Achieve cheap and safe road transportation while ensuring customer satisfaction and alternative paths'.

Grid operators

Operating in the category 'Grid Operators', Grid operators undertake the task of TSO/DSO. Their stated objective is 'Safeguard grid quality', and their performance is gauged by:

- Risks of power outage / grid-congestion reduced.
- Smart charging options facilitated.

Generation Companies (GENCOs)

Identified under 'Grid Operators', the Generation Companies (GENCOs) contributes through Organizations that own and operate power generation assets. They are responsible for producing electricity and are key players in electricity markets. With the integration of EVs—especially through V2G concepts—GENCOs face new opportunities and challenges, as EVs can supply ancillary services and influence generation dispatch. Their strategic purpose, 'To optimize power production and system balancing by adjusting generation schedules and leveraging EV-based ancillary services. They aim to improve system efficiency, reduce peak load impacts, and participate competitively in energy and reserve markets as EVs provide additional flexibility', is evaluated against result indicators like:

- Changes in generation dispatch patterns and peak load reduction.
- Increased revenue or cost savings from ancillary services provided by EVs.
- Improved overall system reliability and reduced need for expensive peaking generation.
- Documented participation in market mechanisms that incorporate V2G services.

EV users or candidates

The role of EV users / candidates falls within the 'Users' group. They are primarily involved in Companies or individuals that own or may own an electric vehicle. Their goal, 'Stimulate electric mobility by enabling charging', shows their influence in the EV sector, and their effectiveness is reflected in indicators like:

- Increased Accessibility of CI
- Growth in number of users of CI.

Residents (non-EV-users)

Classified as part of 'Users', Residents (non-EV-users) has the responsibility of Other non-electric car users. Their efforts are guided by the objective 'Optimize utilization of CI and manage parking pressure', with results measured through increased level of utilization of CI.

Flexibility Aggregators (Virtual Aggregators)

Within the electric vehicle ecosystem, Flexibility Aggregators (Virtual Aggregators) is recognized under 'Market Player/ Operators'. Their function can be described as Entities that develop and implement smart control platforms to coordinate the charging and discharging of EVs, aggregating distributed flexible capacity to provide ancillary grid services. These organizations leverage data, real-time algorithms, and communication protocols (e.g. virtual aggregators in projects like ACDC, [8] to enable EVs to act as dynamic storage assets., while they pursue the objective 'Optimize grid stability and cost-effectiveness by harnessing the aggregated flexibility of EV charging. Their aim is to provide services such as frequency regulation, load balancing, and demand response while ensuring that battery degradation remains minimal and user requirements are met.'. Progress is monitored by indicators such as:

- Demonstrated improvements in grid frequency response and load balancing in field tests.
- Quantifiable revenue from ancillary services (e.g., profit per EV from frequency control, as highlighted in the ACES project, [9]).
- Verified technical performance of bidirectional control systems (e.g., response time and power modulation metrics).
- Validated economic benefits and minimal additional battery degradation through pilot deployments.

Local Flexibility Market Operators

Operating in the category 'Market Player/ Operators', Local Flexibility Market Operators undertakes the task of Entities that design, implement, and manage the local flexibility market platform. They act as intermediaries between distribution system operators (DSOs) and aggregators, coordinating auctions, bid submissions, and market clearings for flexibility services. Their stated objective is 'To enable DSOs to procure reliable and economically viable flexibility services well in advance, supporting network planning and congestion management, by ensuring transparent, efficient, and fair market operations.', and their performance is gauged by:

- Market participation and bid submission rates by aggregators.
- Improved accuracy in flexibility procurement (e.g., reduction in forecast errors).
- Measurable economic benefits from avoided grid reinforcement costs.
- Documented improvements in DSO service activation and network performance.

Market Operators (Local Flexibility Market Operators, Independent Role)

Identified under 'Market Player/ Operators', the Market Operators (Local Flexibility Market Operators, Independent Role) contributes through Independent entities responsible for managing and clearing the local flexibility market. They act as intermediaries between DSOs and aggregators by collecting flexibility service requests, running auctions, and coordinating bid evaluations without disclosing sensitive information like the DSO's willingness to pay. Their strategic purpose, 'To facilitate a transparent, efficient, and fair market for flexibility services that enables DSOs to procure services for congestion management and grid reinforcement deferral. This role ensures that flexibility from distributed resources is reliably and economically integrated into grid planning.', is evaluated against result indicators like:

- Successful clearing of flexibility service auctions (e.g., high participation rates and effective bid matching).
- Measurable reduction in grid operational costs and congestion (e.g., reduced transformer overload events).
- Documented improvements in the economic benefits of flexibility services, such as quantified savings in avoided grid reinforcement investments.
- Positive feedback from DSOs and aggregators regarding market performance and service reliability.

CSOs/commercial parties in the EV chain

The role of CSOs/commercial parties in the EV chain falls within the 'Market Player/ Operators' group. They are primarily involved in Companies that manage the charging infrastructure (charging points) and the services related to it. Their goal, 'Facilitate a positive business case', shows their influence in the EV sector, and their effectiveness is reflected in indicators like:

- CI-costs reduced.
- CI-benefits increased.
- Business case CI improved.

Charging Point Operators

Classified as part of 'Market Player/ Operators', Charging Point Operators have the responsibility of Selling the actual energy to the EV driver and are responsible for the day-to-day operation of charging stations. Their efforts are guided by the objective 'Ensuring efficient charging services for EV users', with results measured through:

- Maximize usage of charging infrastructure (average % of time chargers are in use and energy delivered to users).
- Achieve profitability (Amount of money earned from per charging session or per kWh delivered).

Commercial Vehicle Operators

Within the electric vehicle ecosystem, Commercial Vehicle Operators are recognized under 'Users'. Their function can be described as Organizations and fleet operators managing commercial vehicles (including battery electric trucks and heavy-duty vehicles). CVO often require more space and specialized charging solutions to support efficient, cost-effective logistics and freight operations, while they pursue the objective 'Facilitate the transition to zero-emission commercial transport by deploying tailored charging infrastructure that addresses the unique operational and economic needs of commercial fleets'. Progress is monitored by indicators such as:

- Increased installation of dedicated commercial charging hubs or depot chargers.
- Reduced vehicle downtime and improved operational efficiency.
- Measurable cost savings and environmental performance improvements in fleet operations.

Charging Point Manufacturer

Operating in the category 'Market Player/ Manufacturers', Charging Point Manufacturer undertakes the task of producing the charging equipment. Their stated objective is 'Ensure the charging stations are safe and meet international standards', and their performance is gauged by total EV chargers sold and sales growth compared to previous periods.

Car Manufacturer

Identified under 'Market Player/ Manufacturers', Car Manufacturers develop their charging network and cooperate with charging point operators to ensure that the charging infrastructure is sufficient for the driver needs. Their strategic purpose is to increase battery, driving, and charging efficiency to improve the driving range and meet the consumer expectations.

Develop fast-charging technology to make EVs more convenient', is evaluated against result indicators like growth in electric vehicle sales due to wider availability of charging stations.

Consultancy

The role of Consultancy falls within the 'Market Player/ Services' group. They are primarily involved in giving advice to other stakeholders. Their goal, 'Makes informed decisions on where and how to install EV chargers', shows their influence in the EV sector, and their effectiveness is reflected in indicators like success rate of deployments (X% of recommended projects being completed on time and within budget).

Service Provider

Classified as part of 'Market Player/ Services', Service Provider has the responsibility of Provide access to the large number of different charging point operator and they provide billing services to the drivers. Their efforts are guided by the objective 'Ensuring charging stations are available, working, and easy to locate', with results measured through increased availability of charging stations for users, leading to better convenience and reliability.

Financial Institution

Within the EV ecosystem, Financial Institution is recognized under 'Market Player/ Services'. Their function can be described as Provides loans or project financing for EV charging station deployment., while they pursue the objective 'The objective is to make a profit by providing loans or financing to EV charging projects that are expected to grow and generate income'. Progress is monitored by indicators such as earn revenue from interest payments on loans provided for EV charging infrastructure projects.

Real Estate (Owners/Managers)

Operating in the category 'Market Player/ Services', Real Estate (Owners/Managers) undertakes the task of Entities that own and manage commercial, residential, or mixed-use properties. They play a pivotal role in integrating EV charging infrastructure within urban spaces, optimizing space usage, and enhancing energy management within buildings. Their stated objective is 'Leverage the deployment of sustainable charging infrastructure to increase property value, attract new tenants or users, and support energy efficiency and renewable energy integration', and their performance is gauged by:

- Increased property values; higher occupancy or foot traffic around charging-enabled sites.

- Measurable improvements in building energy performance and carbon footprint reductions.

3 EVSE CLASSIFICATION FRAMEWORK

Nowadays the market is flooded with a variety of charging technology and solutions. This section examines classification frameworks designed to meet different needs and their adaption to different countries and environments. The decision to enlarge the charging equipment infrastructure and the selection of the right solutions is not an easy task. In this Section we aim to provide a common ground for making this decision. A crucial point to the decision is identifying the relevant indicators to look at. Figure 3.1 shows a selection scheme which identifies the most suitable indicators based on the use-case requirements. By selecting the access level, power, location and availability of services the scheme provides the most suitable KPIs for a particular Stakeholder group. These KPIs can then be used by decision support tools to identify the most suitable technological solutions.

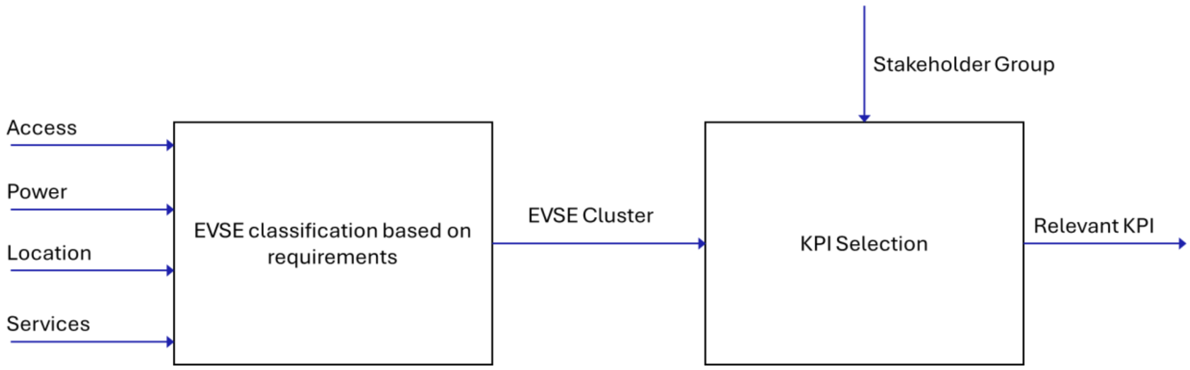


Figure 3.1: EVSE KPI Selection Process

Two relationships are crucial to this scheme: the correlation between the selected characteristics and the charging equipment cluster and the correlation between clusters, stakeholder groups and the relevant KPIs. This Section is focused on the first part of the scheme while the second part will be treated in Section 4.

3.1 The need for classification

EVSEs come in a wide variety of types and use-cases, making a clear classification framework essential, [10] [11] [12]. EVSE can range from low-power AC supply equipment for overnight home use to ultra-fast DC stations along highways, as well as emerging technologies like wireless pads and bidirectional (V2G) systems. Each of these has distinct technical characteristics, user patterns, and impacts on the electric grid. Classifying EVSE according to key characteristics is important for several reasons:

- Handling Technical Diversity: EVSE technologies differ in power levels, charging modes, and connectivity, which affects performance and compatibility, [10] [11] [12].

Conventional AC chargers (7–22 kW) dominate home, workplace, and depot charging due to low cost and ease of installation, whereas 50–350 kW DC fast chargers are used on inter-city corridors and logistic hubs for quick top-ups [10] [12] [13] [14]. These high-power stations introduce unique challenges (cooling, power quality, etc.) that do not apply to lower-power units. A classification helps stakeholders recognize these technical differences and set appropriate expectations for each category of charger.

- Aligning with User Behaviour and Needs [10] [15] [16]: Different charging categories correspond to different usage patterns and driver needs. Residential or slow chargers support frequent, long-duration sessions (e.g. overnight charging) that align with typical daily driving and parking habits. Public fast chargers, by contrast, serve drivers who need rapid energy replenishment on the go, with short dwell times. Public AC chargers installed at workplaces, malls, or curb side essentially extend home-charging behaviour into urban settings, but with higher session turnover due to multiple users sharing the stations. Classifying EVSE by context (home, work, commercial, highway, etc.) is crucial so that planners and operators can design the charging experience appropriately. For instance, a slow charger might be acceptable in a workplace parking lot where cars stay for hours, but the same would frustrate users at a highway rest stop. Indeed, a charging site open to all drivers with no on-site amenities and only low-voltage chargers can lead to long queues and frustration during peak times. By contrast, many modern charging hubs now include cafes or lounges to improve the user experience during fast-charging stops. A robust classification framework makes these differences explicit, ensuring user needs (convenience, wait times, facility availability) are met for each category of EVSE.
- Managing Grid Integration and Infrastructure Challenges: From a power system perspective, not all EVSE are equal, their grid impacts vary significantly [17] [18] [19] [20]. Classifying EVSE helps distribution system operators and utilities anticipate and manage these impacts. For example, clusters of many “slow” AC chargers in residential areas can collectively create high evening peak loads if unmanaged, overloading local transformers or causing voltage drops. In fact, uncontrolled clustering of 7–22 kW home chargers in dense neighbourhoods can already strain urban distribution networks. Conversely, high-power DC stations may draw hundreds of kW per charger, potentially requiring dedicated transformers or medium-voltage grid connections. Such heavy-duty sites raise issues of grid capacity upgrades and power quality compliance, often at significant cost. By classifying EVSE according to their power level and grid service capabilities, planners can apply the right grid integration

measures – from smart charging and peak shaving in the case of numerous AC chargers, to upgraded infrastructure and energy storage buffering for clusters of ultra-fast chargers. In summary, classification allows a system-level view: it groups together chargers with similar load profiles and flexibility potential, so that grid integration strategies (transformer sizing, demand response signals, etc.) can be tailored to each category.

- Supporting Stakeholder Objectives and KPIs: EVSE classification ensures that each stakeholder – be it a CPO, electric utility/DSO, EV user, or municipal planner – can focus on the performance metrics relevant to the type of charging in question, [21] [22] [23] [24]. Different EVSE categories come with different key performance indicators (KPIs) and success criteria. For example, in public charging clusters where access is open to all and charging is relatively slow (low voltage, no special services), a critical KPI is the waiting probability, as demand can be high and users have little to do while waiting in line. By contrast, in a private depot setting or a “smart” charging cluster, metrics like energy flexibility or market participation rate become more relevant. The AHEAD project’s framework explicitly maps certain KPIs to specific EVSE clusters – for instance, protocol compliance (OCPP/ISO 15118) is tracked mainly for clusters intended to provide grid services, and user consent rate for flexibility programs is meaningful where EVSE are part of demand-response schemes. This alignment illustrates why classification is needed: it links the technical and operational traits of an EVSE category to business and policy goals. It also helps in identifying gaps – for example, if a particular class of chargers (say public fast chargers on highways) shows low utilization or user satisfaction, stakeholders can pinpoint that category for improvements in business model or amenities.

- Informing Business Models and Investment Decisions: Finally, classifying EVSE by use-case and capability guides investors and policymakers in making sustainable deployment choices, [10] [12] [11]. Each EVSE category has different cost structures and revenue opportunities. Highway ultra-fast stations entail high upfront costs and rely on steady throughput (and often public co-funding) to be viable. Private residential or fleet chargers, in contrast, have lower costs and may not generate direct revenue, but they provide value in convenience and can even serve as grid assets if aggregated. New business models have evolved around these differences: for example, “Charging-as-a-Service” offerings allow site hosts to install chargers with third-party management in exchange for fees – a model well-suited for fleets and apartments where charging is a needed amenity but not the core business. Likewise, EVSE that are equipped for bidirectional power flow open ancillary service revenues by selling energy or balancing services back to the grid. Only certain classes of chargers and cars (with appropriate communication and control capabilities) can participate in such programs. By classifying infrastructure, cities and companies can identify which charger type fits their business case. For instance, deploying a network of slow AC chargers in dense residential areas can be a cost-effective strategy to meet urban charging needs – studies show it can reduce overall grid upgrade costs by up to 40% [25]while improving driver satisfaction by matching long parking durations. On the other hand, meeting inter-city travel demand requires fast DC chargers along highways, which may need government support and strategic placement every few dozen kilometres. In short, classification provides a strategic map to match the right investment and business model to the right kind of charging equipment.

3.2 Using Classification to Guide EVSE Deployment

When installing new charging equipment, a clear classification of EVSE options plays a pivotal role in choosing the right solution for the situation. Rather than a one-size-fits-all approach, planners should leverage the classification framework to ensure the selected charger aligns with technical requirements, user expectations, and system constraints of the intended site. The following considerations illustrate how classification guides the decision-making process:

1. Identify the Use-Case and Access Type: Determine the primary context of the installation – is it for private use (e.g. a home or a restricted fleet depot) or public use (open to all drivers)? Is it meant to serve daily commuting needs (longer parking, frequent use) or enable long-distance travel (quick stops)? Classifying the site in this way narrows down the EVSE category. For example, a public community charger in an urban residential area might fall under a “public AC – residential” class, whereas a highway rest stop charger would be in a “public high-power – transit corridor” class. This distinction drives many other requirements (power level, standards, etc.).
2. Match the Power Level to User Dwell Time and Volume: Classification helps match charger power output to how long vehicles will typically be parked and how many users will rotate through. In settings with long dwell times (overnight at home or multi-hour workplace parking), a Level 2 AC charger (up to ~22 kW) usually suffices, delivering ample energy over several hours. In contrast, sites meant for quick turnarounds need DC fast chargers (50 kW, 150 kW, 350 kW, etc.) to minimize wait time. Using the classification, an installer can select equipment that provides the necessary charging speed without over- or under-provisioning. This not only optimizes the user experience but also avoids wasting resources – for instance, deploying an expensive high-power

station in a location where cars naturally stay for 8 hours would be overkill, while to slow a charger at a busy transit location would lead to queues and driver dissatisfaction. A balanced deployment strategy, as evidenced by real-world studies, is to use fast DC units for rapid highway charging and abundant slower AC units in residential or downtown areas; this mix leverages each class's strengths and keeps both grid stress and user anxiety in check.

3. Assess Grid Connection and Infrastructure Needs: Each EVSE class has typical electrical supply requirements that must be feasible at the installation site. Through classification, one can anticipate whether a charger will run on low-voltage distribution or require a medium-voltage feed. For example, clustering several 22 kW AC chargers in a garage may only require an upgrade of the local low-voltage feeder, whereas adding a 350-kW station could demand a new transformer or even a direct medium-voltage connection. Planners should use the EVSE category to check local grid capacity and plan any necessary reinforcements. Moreover, classification indicates where smart charging or energy storage might be needed: a category of "many residential AC chargers" suggests implementing load management or time-of-use incentives to prevent synchronized peaks, while a "high-power charging hub" category might incorporate battery buffers or renewable integration to mitigate grid impact. By following the guidelines associated with each EVSE class, installers can ensure the site's electrical infrastructure is prepared and cost-effective measures (like dynamic load balancing within a cluster of chargers) are in place.
4. Ensure Required Communication and Flexibility Capabilities: The classification framework also differentiates EVSE by their level of intelligence and connectivity. If the use-case envisions participation in grid services or advanced user interactions, the chosen equipment should belong to a class that supports standardized communication protocols (such as OCPP 2.0.1 and ISO 15118) and possibly bidirectional power flow. For instance, a "flexibility-enabled" charger class implies the station can respond to external signals (to modulate charging for demand response) or even inject power back to the grid. Installing a charger from this class could unlock additional value streams, as operators can aggregate these chargers to provide frequency regulation, voltage support, or reserve power to the grid. On the other hand, if the primary goal is simple, reliable charging with minimal complexity (e.g. a basic public charging pole on a street), a less sophisticated EVSE class may be sufficient. In all cases, matching the charger's capabilities to the anticipated service level is vital – there is no need to pay for vehicle-to-grid functionality in a location that will never use it, and conversely, failing to choose

a smart charger for a site that could greatly benefit from energy management would be a missed opportunity.

5. Consider User Amenities and Site Experience: Classification should inform not just the charger hardware but the supporting facilities around it. Certain classes of public charging (particularly those in out-of-town or highway locations) may warrant additional amenities to improve the charging experience. For example, a charging station classified under “transit corridor – high power, no nearby services” highlights a need to provide at least basic amenities (lighting, toilets, shelter, information) or co-locate with convenience services, so that drivers are more comfortable during the short but inevitable waiting periods. In urban or retail settings, chargers might be integrated into parking facilities that already offer things to do (shopping centres, coffee shops), which aligns with a different class of EVSE (e.g. “public AC – commercial zone”) where user engagement is less of an issue. By consulting the classification, installers and local authorities can anticipate these human-centric aspects – ensuring that each charging site is not only technically sound but also positioned to maximize driver satisfaction and adoption.
6. Align with Business Model and Policy Incentives: Finally, choosing the right EVSE class means aligning the project with the appropriate business model and any available incentives. Public fast-charging stations, for instance, might qualify for government grants or need a pricing strategy to ensure profitability given their high-power costs. Private or semi-private chargers (like those in apartment complexes or workplaces) might instead be justified by added property value or employee/customer satisfaction, rather than direct revenue alone. If a charging installation is part of a larger energy or sustainability plan (for example, a city aiming to use EVs for grid balancing), selecting equipment from a class that supports those goals (smart, networked, capable of future upgrades) is crucial. Policymakers are increasingly recognizing these nuances – funding programs often distinguish between community AC charging and corridor DC charging, acknowledging that each serves a different purpose in the overall ecosystem. Thus, by using the EVSE classification framework as a guide, decision-makers can ensure that the chosen charger not only fits the immediate use-case but also aligns with broader economic and policy contexts.

3.3 Main characteristics used for classification

The classification of EVSE is a critical step in assessing their technical capabilities, functional role, and contribution to power system flexibility. Literature indicates that the most relevant dimensions for EVSE categorization include access type, power level, location, and service capability, all of which influence the charging behaviour of end users, grid interaction, and business models.

Charging infrastructure varies widely in terms of speed, cost, and location, with strategic deployment depending on whether the objective is residential convenience, corridor coverage, or commercial accessibility. Publicly accessible chargers are a key driver of EV adoption, with per-capita charger availability showing a stronger correlation with uptake than direct financial incentives. Private chargers, while dominant in early adoption phases, often lack advanced flexibility features unless integrated into smart energy systems [10].

From a power system perspective, EVSE can also be classified based on grid connection voltage (LV, MV, HV), which determines potential charging power and grid impact. Flexibility-capable EVSE—those supporting smart charging or bidirectional V2G operation—can provide ancillary services such as load shifting, congestion management, and frequency regulation. Strategies like price-based control, emission-optimized charging, and PV self-consumption optimization can enhance both economic returns and system stability.

Integration within broader smart energy systems positions EVSE not only as a charging point but as an active element in sector coupling—linking transport, electricity, and heating systems. When connected to medium or high voltage networks, EVSE at commercial hubs or fleet depots can deliver high-capacity charging and provide substantial flexibility to distribution system operators. As the rate of EV users increases, housing associations and condominiums where parked most of the time, AC charging will also provide a considerable portion of flexibility services. This also applies to other parking clustering features, ie in commercial districts. Thus, the spatial planning of charging infrastructure may provide considerable flexibility services, if properly designed.

The classification framework therefore needs to capture:

- Access Type: Public or private availability.
- Service Capability: Provision of smart charging, demand response, V2G, or renewable integration.
- Voltage Level: Determines power delivery and potential for high-capacity operation.
- Location Context: Residential, commercial, industrial, or highway environments, influencing usage patterns.
- Operational Role: Passive consumption versus active flexibility provision.

By structuring the classification around these characteristics, it becomes possible to map each EVSE category to relevant KPIs and to identify the clusters that are most effective for supporting both transport electrification and power system flexibility goals.

Table 3: EVSE Retained Clusters

Access	Services	Voltage	Location	Main Cluster	Sub Cluster
Public	Yes	LV	Residential areas	CL1	CL1.1
Public	Yes	MV/HV	Residential areas	CL2	CL2.1
Public	No	LV	Residential areas	CL3	CL3.1
Public	No	MV/HV	Residential areas	CL4	CL4.1
Private	Yes	LV	Residential areas	CL5	CL5.1
Private	No	LV	Residential areas	CL7	CL7.1
Public	Yes	MV/HV	Commercial zones	CL2	CL2.2
Public	No	LV	Commercial zones	CL3	CL3.2
Public	No	MV/HV	Commercial zones	CL4	CL4.2
Private	Yes	LV	Commercial zones	CL5	CL5.2
Private	Yes	MV/HV	Commercial zones	CL6	CL6.2
Private	No	LV	Commercial zones	CL7	CL7.2
Private	No	MV/HV	Commercial zones	CL8	CL8.2
Public	Yes	LV	Industrial facilities	CL1	CL1.3
Public	Yes	MV/HV	Industrial facilities	CL2	CL2.3
Public	No	LV	Industrial facilities	CL3	CL3.3
Public	No	MV/HV	Industrial facilities	CL4	CL4.3
Private	Yes	LV	Industrial facilities	CL5	CL5.3
Private	Yes	MV/HV	Industrial facilities	CL6	CL6.3
Private	No	LV	Industrial facilities	CL7	CL7.3
Private	No	MV/HV	Industrial facilities	CL8	CL8.3
Public	Yes	LV	Highways	CL1	CL1.4
Public	Yes	MV/HV	Highways	CL2	CL2.4
Public	No	LV	Highways	CL3	CL3.4
Public	No	MV/HV	Highways	CL4	CL4.4
Public	Yes	LV	Remote areas	CL1	CL1.5
Public	Yes	MV/HV	Remote areas	CL2	CL2.5
Public	No	LV	Remote areas	CL3	CL3.5
Private	Yes	LV	Remote areas	CL5	CL5.5
Private	Yes	MV/HV	Remote areas	CL6	CL6.5
Private	No	LV	Remote areas	CL7	CL7.5
Private	No	MV/HV	Remote areas	CL8	CL8.5

3.4 EVSE clusters

The classification framework developed in Section 3.2 provides a structured approach to organizing EVSE types across dimensions such as access, voltage level, services, and location. While this framework captures the theoretical range of possible combinations, not all of them are meaningful in practice. To ensure analytical clarity and real-world applicability, the classification has been refined by excluding combinations that are technically inconsistent, economically unfeasible, or redundant.

Purpose of refinement

The refinement serves two main objectives:

- Practical feasibility: Certain combinations, although possible in theory, are not deployed because they conflict with user behaviour, grid integration requirements, or the economic logic of charging infrastructure.
- Analytical clarity: By eliminating unrealistic overlaps, the classification remains coherent and avoids categories that could distort subsequent KPI assessment, scenario modelling, or planning exercises.

This ensures that the framework is not only academically consistent but also operationally relevant for decision-makers, operators, and investors.

Refinement process

The refinement process was guided by insights from recent research and practical deployment trends, [10] [12] [11]. Literature shows that EVSE categories must reflect actual usage patterns, user needs, and grid limitations rather than theoretical possibilities. It is also emphasized that charging infrastructure must be planned in line with accessibility requirements and demand profiles: for example, high-power highway chargers must be universally accessible and service-equipped, while residential charging is naturally linked to low-voltage, private contexts.

From a grid and infrastructure perspective, research confirms that medium- and high-voltage charging points involve significant costs and are justified only in public, high-utilization settings, [18] [19] [20]. Their deployment in private or service-free contexts is therefore not viable. Similarly, categories that implied redundant overlaps with existing clusters were excluded to streamline the classification.

The following sub clusters were excluded from Table 3:

- CL1.2 (Public, Services, LV, Commercial zones)
  Low-voltage chargers with full-service provision in commercial zones are redundant, as these locations typically require medium/high voltage to meet higher charging demand and turnover rates.
- CL4.5 (Public, Services, MV/HV, Highways)

While services are necessary on highways, classifying a specific MV/HV combination here overlapped with other defined clusters. To avoid redundancy, this subcluster was excluded.

- CL5.4 (Private, Services, MV/HV, Remote areas)
  High-voltage private charging with services in remote areas lacks feasibility. Private installations in such locations are unlikely to justify the cost of MV/HV connections, and public accessibility is more suitable.
- CL6.1 (Private, Services, MV/HV, Residential areas)
  Providing services in a MV/HV, private context has a limited application considering the high investment costs for infrastructure...
- CL6.4 (Private, Services, MV/HV, Highways)
  Similar to CL6.1, the presence of services in a private MV/HV in highway setting is contradictory, as MV/HV infrastructure presupposes broader accessibility and higher utilization.
- CL7.4 (Private, No Services, LV, Highways)
  A private, service-free high-power charging station on highways is illogical. Highway infrastructure must be public, accessible, and service-equipped to meet long-distance travel needs.
- CL8.1 (Private, No Services, MV/HV, Residential areas)
  A private MV/HV installation with no services in residential areas is not feasible as residential areas usually rely on low voltage system.
- CL8.4 (Private, No Services, MV/HV, Highways)
  Similar to CL7.4, MV/HV chargers without services in a private context are not practical, as such infrastructure is only justifiable in high-demand, service-supported public settings.

Justification for retained clusters

The clusters that remain after refinement represent the core, realistic categories of EVSE deployment:

- Residential charging
  Low-voltage chargers in private or semi-private contexts remain essential, as they represent most charging events due to long vehicle dwell times. These clusters also align with user behaviour, since most EV users prefer home charging where feasible.
- Commercial and workplace charging, publicly accessible charging in commercial zones, often with services and medium voltage, plays an important role in supporting

daytime charging needs and balancing demand between home and highway usage, [10] [12] [15].

- Industrial and fleet charging, dedicated chargers for industrial facilities and fleet depots are justified, as these users often require controlled, high-capacity charging for logistics and company vehicles.
- Highway fast charging, public high-voltage chargers along highways remain critical to enabling long-distance mobility. These clusters align with policy priorities for transnational charging corridors and ensure range confidence for EV drivers.
- Remote or rural public charging, in sparsely populated areas, lower-power public chargers with limited services remain relevant to ensure accessibility, even if utilization is lower. These clusters are particularly important for inclusivity and ensuring full geographic coverage.

By retaining these clusters, the classification captures both the core mass-market needs (residential and urban charging) and the strategic infrastructure needs (highway and remote area coverage), while also accounting for specific cases such as industrial fleets.

Implications of refinement

The exclusion of these clusters improves the classification in several ways:

- Consistency with user needs
  The remaining clusters correspond directly to real charging practices, such as public fast charging on highways or private low voltage charging in residential areas.
- Technical and economic viability
  Redundant or impractical configurations, particularly those involving unjustified MV/HV deployment, have been eliminated.
- Policy and market alignment
  The refined framework mirror the priorities of accessibility, interoperability, and cost-effectiveness that are guiding infrastructure rollout in practice, [21] [22] [23] [24].
- Improved analytical usability.
  The streamlined classification enhances its value as a tool for KPI evaluation, business model analysis, and flexibility assessments.

4 KEY PERFORMANCE INDICATORS (KPI)

A KPI is a measurable value that shows how effectively a specific goal is achieved by an individual, team, or organization. KPIs help track progress. They identify areas for improvement, and guide decision-making. The purpose of a KPI is to turn a broad goal (e.g., “improve customer satisfaction”) into a measurable result which can be compared to a defined objective. Depending on the area of interest, different type of KPI can be identified (e.g., financial KPIs, operational KPIs, Customer KPIs, etc.). Good KPIs are usually specific, measurable, achievable, relevant, and time bound.

In this Section a comprehensive set of KPIs will be identified. Their explanation and calculation formula will be given and the relation between KPIs and EVSE clusters will be emphasized.

4.1 Comprehensive list of KPIs

The KPIs are shown in the tables below, arranged based on the EVSE performance factors they measure. KPIs are classified based on the following characteristics:

- **Name:** it represents a brief, descriptive name of the KPI
- **Stakeholders:** represent primary stakeholders interested in the objective (i.e., DSOs, TSOs, CSOs, EV fleet operators, municipalities).
- **Access:** is the ownership type for which the KPI is relevant
- **Voltage Level:** represent the voltage level at which the KPI applies (i.e. LV, MV, HV, Transmission Level)
- **Location Type:** represent typical locations that this KPI may impact (e.g., residential areas, commercial zones, industrial facilities, highways, remote areas).
- **Flexibility Services:** represent if the KPI is linked to the flexibility services, such as demand response, peak shaving, load shifting, V2G, etc.

For each KPI a calculation formula and the necessary explanations are also provided.

4.1.1 Availability of the EVSE

Table 4: KPIs that assess the availability of the EVSE.

ID	Name	Stakeholders	Access	Voltage Level	Location Type	Flexibility Services
1	Waiting probability	CSO, EV users	Public	LV, MV, HV	Urban, Rural	NO
2	Location accuracy	CSO, EV users	Public	LV, MV, HV	Urban, Rural	NO

3	Wait time	CSO, EV users	Public	LV, MV, HV	Urban, Rural	NO
4	Occupancy Rate	DSO, CSO, EV Fleet Operators, Municipalities	Public	LV, MV	Commercial Zone, Highways	Yes
5	Idle Time	DSO, CSO, EV Fleet Operators, Municipalities	Public	LV, MV	Commercial zones, Industrial facilities, Highways, Remote areas	NO
6	Availability Factor	DSO, TSO	Public, Private	LV, MV, HV	Commercial zones, Industrial facilities, Highways, Remote areas.	NO

The description, objective, and formula for each KPI are provided below:

- ***Waiting probability (% of time)***

The aim of this KPI is to approximate the likelihood of waiting to access a functional and unoccupied charger [26]. This KPI is intended to help address customer pain points related to accessing a charger. Formula for calculation waiting probability:

$$\left(1 - \Pi_i^P \left(\frac{\sum_j^T A_j}{T}\right)_i\right) \cdot 100$$

Where:

A: time (seconds) the port is available (i.e., port is not in use, under repair, nor out of service)

j = each time step (seconds), i = each individual charging port

T = time (seconds) assessed in hourly blocks

P = total number of charging ports at a station

- ***Location accuracy (meters)***

Difference between the geolocation of EVs charging at the EVSE or charging station and the EVSE or charging station geolocation published by the CSO [26]. This KPI addresses the effort to locate an EVSE. Formula for calculating location accuracy:

$$3963 \cdot arcos[(\sin(EVSE\ lat) \cdot \sin(EV\ lat)) + \cos(EVSE\ lat) \cdot \cos(EV\ long - EVSE\ long)]$$

EVSE lat/long: EVSE port or charging station latitude and longitude provided by the CSO
EV lat/long: Latitude and longitude of an EV when connected to the EVSE port, or any EVSE port at the charging station.

- ***Wait time (minutes, seconds)***

Time to access a functional charging port at a site [26]. This KPI addresses the time required to access an available, functional charger. Formula for calculating wait time:

$$t_{attempt,i} - t_{arrival,i}$$

$t_{arrival}$: timestamp when a vehicle arrives at a charging station
$t_{attempt}$: timestamp when a charge attempt is made.

- ***Occupancy Rate (%)***

Percentage of time a charger is occupied, regardless of whether charging is active [27] [28]. Indicates how effectively chargers are utilized and helps stakeholders to identify if additional chargers are needed. This KPI impact in location such as commercial zone and highways. At commercial zone charging stations attract customers and increase business traffic. High occupancy means for demand more chargers to serve visitors. Highways directly impact driver convenience and grid stability. Flexibility services link to this KPI is load shifting which directly affects occupancy distribution by shifting charging demand from peak times to off-peak periods. The formula for calculating occupancy rate:

$$\frac{\text{Total Time a Vehicle is Connected}}{\text{Total Available Time}} \cdot 100$$

Total Time port is occupied: Sum of all hours that a vehicle's connector is mated to the port;
Total Available Time: Time in hours the port was powered on and ready for use.

- ***Idle Time (%)***

Measures the percentage of time a charger is occupied but not actively charging [27]. The objective is to minimise percentage of time a charger is occupied but not actively charging. This ensures that each charger can serve more customers per day. As a result, overall revenue increases. Formula for calculating Idle time:

$$\frac{(\text{Total connection time } - \text{ Total charging time})}{(\text{Total connection time})} \cdot 100$$

Total Connection Time: Time for which the EV is plugged into the charging station but is not actively charging. [27]
Total Charging Time: Time during which an EV is actively drawing power from a specific charger of a station.

- ***Availability Factor***

Percentage of time EVSE is available to provide flexibility services during contracted periods. Indicates the dependability of EVSE as a flexibility resource [29] EV charging stations are dependable and can be used to help the grid to be stable (especially during times when energy demand is high). Formula for calculating availability factor:

$$\frac{\text{Hours EVSE was available for activation}}{\text{Total contracted service hours}} \cdot 100$$

Hours EVSE was available for activation: Number of hours during the contracted service period when the EVSE could deliver flexibility services, if requested.
Total contracted service hours: Total number of hours during the agreed contract period when the EVSE is supposed to be available for flexibility services.

4.1.2 Effective and successful charging sessions

Table 5: KPIs associated with effective and successful charging sessions.

ID	Name	Stakeholders	Access	Voltage Level	Location Type	Flexibility Services
1	Charge start success	CSO, EV users	Public	LV, MV, HV	Urban, Rural	NO
2	Charge start time	CSO, EV users	Public	LV, MV, HV	Urban, Rural	NO
3	Charge end success	CSO, EV users	Public	LV, MV, HV	Urban, Rural	NO
4	Session Success	CSO, EV users	Public	LV, MV, HV	Urban, Rural	NO
5	Extended charge time	CSO, EV users	Public	LV, MV, HV	Urban, Rural	NO
6	First-time session success	CSO, EV users	Public	LV, MV, HV	Urban, Rural	NO
7	Visit success	CSO, EV users	Public	LV, MV, HV	Urban, Rural	NO
8	Charging Power	DSO, EV Fleet Operators, Municipalities	Public, Private	LV, MV	Residential areas, Commercial zones, Industrial facilities, Highways, Remote areas	NO

9	Charging Efficiency	DSO, EV Fleet Operators, Municipalities	Public, Private	LV, MV	Residential areas, Commercial zones, Industrial facilities, Highways, Remote areas	NO
10	Charging Session Duration	DSO, EV Fleet Operators, Municipalities	Public, Private	LV, MV	Commercial zones, Industrial facilities, Highways, Remote areas	NO

The description, objective, and formula for each KPI are provided below:

- ***Charge start success (%)***

Time required for an EVSE to begin delivering power after a charge attempt is initiated [26]. This KPI addresses the time required to start a charging session. Formula for calculation charge start success:

$$\frac{\sum EVSE\ success\ attemps\ DP}{EVSE\ total\ attemps} \cdot 100$$

EVSE success attempts DP: EVSE port charge attempts that successfully start power delivery
EVSE total attempts: EVSE port charge attempts
Charge attempt: a customer's attempt to start a charging session by either (a) plugging the EVSE connector into the EV or (b) presenting valid credentials and/or payment or taking another appropriate action to authorize a charging session
Start of power delivery: the instant when electricity starts being transferred from EVSE to EV

- ***Charge start time (seconds)***

Time required for an EVSE to begin delivering power after a charge attempt is initiated [26]. This KPI addresses the time required to start a charging session. Formula for calculation charge start time:

$$t_{power,i} - t_{attempt,i}$$

t_{power}: timestamp when power delivery begins

$t_{attempt,i}$: timestamp when a charge attempt begins.

- ***Charge end success (%)***

Percent of charging sessions that successfully complete [26]. This KPI addresses the effort required to receive a complete charge. Formula for calculating charge end success:

$$\frac{\sum EVSE\ success\ attemps\ \ ES}{\sum EVSE\ success\ attemps\ DP} \cdot 100$$

EVSE success attempts ES: EVSE charge attempts that result in a charging session ending successfully

EVSE success attempts DP: EVSE port charge attempts that successfully start power delivery

A session ending successfully: a charging session that has a termination due to customer intervention as defined in OCPP or by reaching an energy or State of the Charge (SoC) limit and the EV can be disconnected from the EVSE

- ***Session Success (%)***

Percent of charge attempts that successfully start a charging session and the charging session goes on to successfully complete [26]. This KPI encompasses both charge start success and charge end success; thus, it provides an assessment of the overall effort required to complete a charging session. Formula for calculating session success:

$$\frac{\sum EVSE\ succes\ attemps\ \ ES}{EVSE\ total\ attemps} \cdot 100$$

EVSE success attempts ES: EVSE charge attempts that result in a charging session ending successfully

EVSE total attempts: ΣEVSE port charge attempts.

- ***Extended charge time (minutes, seconds)***

The time a charging session is extended due to power limitations of the EVSE [26]. This KPI addresses the time required to complete a charging session. Formula for calculating extend charge time:

$$\left(T - \left(\frac{E}{\frac{E}{T} - SPE}\right)\right) \cdot 3600$$

SPE (session power error): error between power delivered by EVSE port and power an EV can accept throughout the session (kW)

E: charging energy delivered to EV (kWh)

T: total time during a session when energy is transferred from EVSE to EV (hours)

- ***First-time session success (%)***

Percent of first charge attempts that successfully start a charging session and the charging session goes on to successfully complete the first charge attempt by a customer at a charging port for each EV visit to a charging station [26]. This KPI encompasses both charge start success and charge end success. Formula for calculating first-time session success:

$$\frac{\sum First\ time\ EVSE\ success\ attemps\ ES}{EVSE\ total\ attemps} \cdot 100$$

First time EVSE success attempts ES: First time EVSE port charge attempts that result in charging session ending successfully
EVSE total attempts: ΣEVSE port charge attempts.

Charge attempt: a customer's attempt to start a charging session by either (a) plugging the EVSE connector into the EV or (b) presenting valid credentials and/or payment or taking another appropriate action to authorize a charging session.

- ***Visit success (%)***

Percent of visits to a charging station where at least one charge attempt successfully starts a charging session (i.e., result in an EVSE starting to deliver power to an EV) and where the charging session goes on to successfully complete [26]. This KPI encompasses both charge start success and charge end success. Thus, it provides an assessment of the overall effort required to complete a charging session. Formula for calculating visit success:

$$\frac{\sum EV\ visit\ charging\ session\ ES}{\Sigma\ EV\ station\ visit} \cdot 100$$

EV visit charging session ES: EV visit to a charging station that result in a charging session ending successfully
EV station visit: a distinct visit to a charging station (i.e., period of time the customer's EVs spends at the station between arrival and departure), during which the customer makes at least one charge attempt.

- ***Charging Power***

The power capacity of the charger, typically measured in kilowatts (kW) [13]. The objective is to have higher charging power (means faster charging), which reduces waiting times.

- ***Charging Efficiency***

The ratio of energy delivered to the EV battery compared to the energy drawn from the grid [13]. The objective of this KPI is to maximise energy efficiency and minimize power losses during the charging process. Formula for calculating charging efficiency:

$$\frac{\text{Energy Stored in Battery (kWh)}}{\text{Energy Drawn from th Grid (kWh)}} \cdot 100$$

Energy Stored in Battery: The amount of energy stored inside the Electric Vehicle battery after the charging process.
Energy Drawn from the Grid: The amount of energy taken from the grid during the charging session.

- ***Charging Session Duration***

The average time an EV remains plugged in per charging session. Helps in optimizing scheduling and reducing congestion at charging stations [13]. Formula for calculating charging session duration:

$$Plug\ out\ time - Plug\ in\ Time$$

Plug-in Time: Time when the EV charging cable is connected to the EVSE and the session starts (the vehicle is physically plugged in, not always the moment when the charging starts).
Plug-out Time: Time when the charging cable is disconnected from the EVSE and the session ends (the vehicle is physically unplugged, not always the moment when the charging ends).

4.1.3 EVSE Usage

Table 6: KPIs that measure EVSE usage.

ID	Name	Stakeholders	Access	Voltage Level	Location Type	Flexibility Services
1	Utilization Rate	DSO, TSO, CSO, EV Fleet Operators, Municipalities	Public, Private, Community	LV, MV, HV	Urban, Rural	Yes
2	Turnover	DSO, CSO, EV Fleet Operators, Municipalities	Public	LV, MV	Commercial zones, Industrial facilities, Highways, Remote areas	NO
3	Turnover from advertisement	DSO, CSO, EV Fleet Operators, Municipalities	Public	LV, MV	Commercial zones, Industrial facilities, Highways, Remote areas	NO
4	Unique users rate	DSO, CSO, EV Fleet Operators, Municipalities	Public	LV, MV	Commercial zones, Industrial facilities, Highways, Remote areas	NO
5	EVSE Participation Rate	DSO, TSO	Public, Private	LV, MV, HV		NO

The description, objective, and formula for each KPI are provided below:

- ***Utilization Rate***

Measures the percentage of time EV charging actively provide services versus idle time. Optimizes infrastructure deployment and ensures alignment with grid needs [14]. The objective is to optimise the use of charging stations by maximizing efficiency, ensuring charging stations are used effectively and not left idle unnecessarily. Peak shaving, demand response, energy arbitrage, load shifting, and valley filling are flexibility services that are linked to this KPI. The final two flexibility services, respectively, limit load during system peaks and absorb excess grid capacity during periods of low demand.

Formula for calculating utilisation rate:

$$\frac{\text{Active service time (hours)}}{\text{Total available time (hours)}} \cdot 100$$

Active service time (hours): time when the EVSE is in use (charging or providing flexibility services).
Total available time (hours): time when charger is operational and ready for use.

- ***Turnover***

Total revenue earned from charging services [27]. Maximize revenue generation from EV charging operations. Formula for calculating turnover:

$$\text{Energy charged (kWh)xTariff Rate (€/kWh)}$$

Energy charged (kWh): Refers to the total energy delivered from the charging station to an electric vehicle during a session.
Tariff Rate (€/kWh): cost per unit of energy (kWh) the user pays for charging at an EVSE.

- ***Turnover from advertisement***

Revenue generated from ads placed at charging stations [27]. Maximize revenue generation from digital presence of charging stations.

- ***Unique users rate (%)***

Unique users refer to the number of distinct EV drivers who have used a particular charging station or network over a given period [27]. The objective of this KPI is to help charging point operators understand how different users access their chargers, indicating the effectiveness of station locations (are they easy to find and convenient for many users) and pricing models (prices are attractive enough to bring in a variety of customers). Formula for calculating unique user rate:

$$\frac{\text{Unique users}}{\text{Total Charging Sessions}} \cdot 100$$

Unique Users = The number of distinct individual users who have used the EVSE over a specific period.

Total Charging Sessions = Total number of times the EVSE was used to charge an EV during the same period.

- ***EVSE Participation Rate***

Percentage of EVSE actively enrolled in flexibility markets. Measures adoption of EVSE as a flexibility resource for grid services [29]. Evaluate how effectively the EVSE is utilized as a flexible resource that can provide services to the grid, such as demand response, peak shaving, or load balancing. Formula for EVSE participation rate calculating:

$$\frac{\text{Number of EVSE enrolled in flexibility markets}}{\text{Total installed EVSE in the region}} \cdot 100$$

Number of EVSE enrolled in flexibility markets: Is the number of EVSE which are connected in flexibility platforms which can receive and respond to grid signals.

Total installed EVSE in the region: Total number of EVSEs physically installed in an area or region.

4.1.4 EVSE flexibility and efficiency

Table 7: KPIs for EVSE flexibility and efficiency

ID	Name	Stakeholders	Access	Voltage Level	Location Type	Flexibility Services
1	Total Energy Delivered	DSO, CSO, EV Fleet Operators, Municipalities	Public, Private	LV, MV, HV	Commercial zones, Industrial facilities, Highways, Remote areas	Yes
2	Peak Power	DSO, CSO, EV Fleet Operators, Municipalities	Public, Private	LV, MV	Commercial zones, Industrial facilities, Highways, Remote areas	Yes
3	Flexibility Activation Efficiency	DSO, TSO	Public, Private	LV, MV, HV	Commercial zones, Industrial facilities, Highways, Remote areas	Yes
4	Cost Efficiency of EVSE Flexibility	DSO, TSO	Public, Private	LV, MV, HV	Commercial zones, Industrial facilities, Highways, Remote areas	Yes

5	Cost Savings from EVSE Flexibility	DSO, TSO	Public, Private	LV, MV, HV	Residential areas, Commercial zones, Industrial facilities, Highways, Remote areas	NO

The description, objective, and formula for each KPI are provided below:

- ***Total Energy Delivered (kWh)***

This is the total energy supplied by the station**.** The objective is to monitor and optimize energy utilization across the EV charging network. Flexibility services linked with this KPI are load shifting and demand response. Formula for calculating total energy delivered:

$$E = P \cdot t \cdot \eta$$

P: Active power, t: time (hours), η: efficiency

- ***Peak Power (ways to reduce peak power)***

Maximum power output (kW) delivered by a charging station during a specific charging session [27]. The objective of this KPI is to monitor and optimize the power delivery. Flexibility services linked with this KPI are peak shaving and load shifting.

- ***Flexibility Activation Efficiency***

Ratio of successfully activated flexibility from EVSEs to total contracted flexibility. Evaluates the reliability of EVSEs in providing grid services [30]. Flexibility services linked with this KPI are frequency containment reserve (FCR), automatic/manual frequency restoration reserve (aFRR and mFRR), replacement reserve (RR), congestion management, voltage control and local balancing.

Formula for calculating flexibility activation efficiency:

$$\frac{\text{Actual Flexibility Delivered (kW)}}{\text{Contracted flexibility (kW)}} \cdot 100$$

Actual Flexibility Delivered: Amount of flexibility (in kW) that the EVSE provided during a flexibility event. [30]

Contracted flexibility: The agreed or promised amount of flexibility (in kW) that the EVSE committed to provide in a flexibility contract.

- ***Cost Efficiency of EVSE Flexibility***

Cost per unit of flexibility (€/kWh) provided by EVSEs compared to traditional resources. Assesses economic viability of EVSE participation in grid services [30]. Flexibility services linked with this KPI are frequency services, congestion management, voltage control, peak shaving, load shifting, energy arbitrage and local balancing.

Formula for calculating cost efficiency of EVSE flexibility**:**

$$\frac{\text{Total cost of EVSE flexibility (€)}}{\text{Total flexibility provided (kWh)}}$$

Total cost of EVSE flexibility: total monetary cost incurred for activating and managing flexibility from EVSE. For example, direct compensation to EV users for providing flexibility (charging less or delaying charge).

Total Flexibility Provided: Total amount of energy that EVSE have provided. For example, load reduction (charging is reduce or delayed).

- ***Cost Savings from EVSE Flexibility***

Cost savings for grid reinforcement because of EVSE's flexibility. Highlights economic benefits of integrating EVSE into flexibility markets [29]. EVSE flexibility saves money by making the grid working more efficiently, without needing expensive upgrades. Formula for calculating cost saving from EVSE flexibility:

$$\text{Estimated grid reinforcement cost without EVSE} - \text{Actual grid reinforcement cost with EVSE}$$

Estimated grid reinforcement cost without EVSE: Projected cost of upgrading the grid if no EVSE flexibility services were available

Actual grid reinforcement cost with EVSE: This is the real cost of grid upgrades needed when EVSE flexibility is used to manage peak loads.

4.1.5 Grid compliance and energy market participation

Table 8: KPIs linked to grid standard compliance and energy market participation.

ID	Name	Stakeholders	Access	Voltage Level	Location Type	Flexibility Services
1	Market Bid Acceptance Rate	DSO, TSO, CSO, EV Fleet Operators, Municipalities	Public, Private, Community	LV, MV, HV	Urban, Rural	Yes
2	Bid Size Adherence	DSO, TSO, CSO, EV Fleet Operators, Municipalities	Public, Private, Community	LV, MV, HV	Residential areas, Commercial zones, Industrial facilities, Highways, Remote areas	Yes

3	Market Transaction Volume	DSO, TSO, CSO, EV Fleet Operators, Municipalities	Public, Private, Community	LV, MV, HV	Residential areas, Commercial zones, Industrial facilities, Highways, Remote areas	Yes
4	Cluster Voltage Compliance	DSO, TSO, CSO, EV Fleet Operators, Municipalities	Public, Private, Community	LV, MV, HV	Residential areas, Commercial zones, Industrial facilities, Highways, Remote areas	Yes
5	Grid Constraint Compliance Rate	DSO, TSO	Public, Private	LV, MV, HV		Yes
6	Imbalance Reduction from EVSE Coordination	DSO, TSO	Public, Private	LV, MV, HV		Yes

The description, objective, and formula for each KPI are provided below:

- ***Market Bid Acceptance Rate***

Measures the percentage of EV flexibility bids accepted by DSO/TSO platforms. Reflects competitiveness of EV offers versus traditional resources [14]. By increasing the acceptance rate of market bids, EVSE operators aim to maximize their participation in energy markets. Flexibility services linked with this KPI are valley filling, peak shaving, energy arbitrage, demand response, power quality and congestion management.

Formula for calculating market bid acceptance rate:

$$\frac{\text{Accepted Bids}}{\text{Submitted Bids}} \cdot 100$$

Submitted Bids: Offers of EVSE sent to the grid operator or market.

Accepted Bids: Offers accepted by grid operator or market.

- ***Bid Size Adherence***

Tracks the percentage of bids meeting regional size thresholds (e.g., Denmark's 10 kW minimum). This KPI ensures small-scale EV clusters (e.g., residential) can participate in markets [14]. Flexibility services linked with this KPI are valley filling, peak shaving, distributed energy resources (DER) power matching, phase balancing, energy arbitrage, reactive power support/voltage regulation. Formula for calculating bid size adherence:

$$\frac{\text{Bids Meeting Size Threshold}}{\text{Total Bids}} \cdot 100$$

Total Bids: Every offer EVSE sends in each period.

Bids Meeting Size Threshold: Those among total bids whose quantity (power in kW or energy in kWh), is at or above the market's minimum.

- ***Market Transaction Volume***

Measures the number of daily flexibility transactions (bids/offers) on platforms like NODES. Indicates market liquidity and stakeholder trust [14]. The objective is to build a trusted flexibility services market in which EV charging assets can reliably trade energy. Flexibility services linked with this KPI are valley filling, peak shaving, DER power matching, phase balancing, energy arbitrage, under/over voltage regulation, emergency power, demand response. Formula for calculating market transaction volume:

$$\frac{\sum \text{Daily Bids}}{\text{Offers on Flexibility Platforms}}$$

Daily Bids: The total count of bids EVSE submits across all markets over a 24-hour period. *Offers on Flexibility Platforms*: The number of distinct offers posted to those platforms for demand-response.

- ***Cluster Voltage Compliance***

Measures the percentage of time clusters maintain voltage within ±5% of nominal levels during service delivery. Ensures power quality and grid stability [14]. Flexibility services linked with this KPI are under/over voltage regulation, voltage unbalance mitigation, reactive power support and power factor control.

Formula for calculating cluster voltage compliance:

$$\frac{\text{Time Within } \pm 5\% \text{ Voltage Band}}{\text{Total Monitoring time}} \cdot 100$$

Time Within ±5% Voltage Band= Time duration (in hours or minutes) during which the measured line voltage at the charger stayed between $0.95 \cdot V_{nominal} - 1.05 \cdot V_{nominal}$

Total Monitoring time: Interval of collected voltage readings.

- ***Grid Constraint Compliance Rate***

Percentage of EVSE activations that avoid violating distribution or transmission grid constraints. Ensures EVSE operations align with grid safety and stability [30]. Flexibility services linked with this KPI are voltage control, congestion management, frequency services (FCR, aFRR, mFRR) and local balancing.
The formula for calculating grid constraint compliance rate is:

$$\frac{\text{Safe activations within grid constraints}}{\text{Total activations}} \cdot 100$$

Safe activations within grid constraints: charging or discharging activation that is successfully executed to stay within defined grid constraints.
Total activation: Total number of attempts made by the EVSE during grid constrained conditions.

- ***Imbalance Reduction from EVSE Coordination***

Measures reduction in system imbalance (MW) due to EVSE-DSO/TSO coordination. Quantifies EVSE impact on balancing grid supply and demand [30]. Helps reduce the imbalance between grid supply and demand. Flexibility services linked with this KPI are aFRR, mFRR, RR, local balancing, demand response and energy arbitrage.

The formula for calculating the imbalance reduction from EVSE coordination is:

$$\text{Imbalance without EVSE (MW)} - \text{Imbalance with EVSE (MW)}$$

Imbalance without EVSE: This is the total grid imbalance (supply ≠ demand) before any coordination from EVSE.
Imbalance with EVSE: This is the total imbalance after EVSEs have been coordinated with the DSO or TSO.

4.1.6 Cybersecurity standards and service agreements

Table 9: KPIs related to cybersecurity standards and service agreements.

ID	Name	Stakeholders	Access	Voltage Level	Location Type	Flexibility Services
1	Cybersecurity Incident Count	DSO, TSO, CSO, EV Fleet Operators, Municipalities	Public, Private, Community	LV, MV, HV	Urban, Rural	NO
2	User Consent Rate	DSO, TSO, CSO, EV Fleet	Public, Private, Community	LV, MV, HV	Urban, Rural	NO

		Operators, Municipalities				
3	Protocol Compliance Rate			LV, MV, HV		
4	Alliance Service Delivery Rate	DSO, TSO, CSO, EV Fleet Operators, Municipalities	Public, Private, Community	LV, MV, HV	Residential areas, Commercial zones, Industrial facilities, Highways, Remote areas	Yes
5	Communication Latency	DSO, TSO	Public, Private	LV, MV, HV		Yes

The description, objective, and formula for each KPI are provided below:

- ***Cybersecurity Incident Count***

Tracks the number of unauthorized access attempts or data breaches per month in CPO-DSO alliances. Ensures compliance with cybersecurity protocols [14]. Ensure secure operation and data protection through monitoring and minimizing cybersecurity incidents. Formula for calculating cybersecurity incident count:

$$\frac{\sum \text{Monthly Unauthorized Access Attempts}}{\text{Data Breaches}} \cdot 100$$

Monthly Unauthorized Access Attempts: all detected attempts to access EVSE system without valid credentials or permissions over one month period.

Data Breaches: is sensitive or confidential information accessed by someone who isn’t authorized to see it.

- ***User Consent Rate***

Measures the percentage of EV users opting into flexibility programs (e.g., dynamic pricing, Time of Use pricing) [14]. The objective is to increase EV user participation and engagement in flexibility programs, such as dynamic pricing, time-of-use tariffs, or demand-response schemes. Formula for calculating user consent rate:

$$\frac{\text{Users Opting in}}{\text{Total Users Approached}} \cdot 100$$

Total Users Approached= The number of unique drivers invited into flexibility programs

Users Opting in=The number of people who accepted to participate into flexibility programs

- ***Protocol Compliance Rate***

Tracks the percentage of chargers compliant with OCPP 2.0.1 or ISO 15118 standards. Ensures interoperability across platforms, [14]. Ensure communication across different platforms and systems using OCPP 2.0.1 or ISO 15118 protocols. Formula for calculating protocol compliance rate:

$$\frac{\text{Number of protocol Compliant Charges}}{\text{Total Chargers}} \cdot 100$$

Number of protocol Compliant Charges: Number of chargers that has implemented protocols like OCPP or ISO 15118

Total Chargers: all charge points in network.

- ***Alliance Service Delivery Rate***

Measures the number of successful service activations (e.g., congestion management, voltage regulation) per CPO-DSO alliance. Evaluates alliance effectiveness in delivering grid services [14]. The objective is to ensure collaborations (alliances) between CPOs and Distribution System Operators (DSOs) in providing critical grid services such as congestion management and voltage regulation. Flexibility services linked with this KPI are valley filling, peak shaving, DER power matching, phase balancing, under/over voltage regulation, voltage unbalance mitigation, reactive power support, emergency power and intentional islanding.

Formula for calculating alliance service delivery rate:

$$\sum \text{Successful Service Activations}$$

Successful Service Activations: Total count of times the charger started a service, like a charging session without error.

- ***Communication Latency***

Time delay (seconds) between TSO/DSO signals and EVSE response. Critical for real-time grid services (e.g., frequency control) [30]. The objective is to ensure real-time data exchange between EV chargers and connected systems. Flexibility services linked with this KPI are FCR, aFRR, mFRR, voltage control, local balancing and emergency power.
Formula for calculating communication latency:

$$\text{Time of EVSE Activation} - \text{Time of Signal Issuance}$$

Time of EVSE activation: Time when the EVSE responds to the signal and changes its behaviour (for example, starts charging or reduces power).
Time of Signal Issuance: Time when the TSO/DSO sends a signal to the EVSE.

4.1.7 Financial and social impact

Table 10: KPI related with financial and social impact.

ID	Name	Stakeholders	Access	Voltage Level	Location Type	Flexibility Services
1	Return of Investment	DSO, CSO, EV Fleet Operators, Municipalities	Public	LV, MV	Commercial zones, Industrial facilities, Highways, Remote areas	NO
2	Social Cost	DSO, CSO, EV Fleet Operators, Municipalities	Public	LV, MV	Commercial zones, Industrial facilities, Highways, Remote areas	NO

The description, objective, and formula for each KPI are provided below:

- ***Return of Investment***

Evaluate the profitability of an investment [27]. The objective is to determine how effectively capital has been used in installing and operating EV charging stations. The Formula for calculating the return of investment is as follows:

$$\frac{(\text{Total Revenue} - \text{Total Cost})}{\text{Total Cost}} \cdot 100$$

Total Revenue: total income earned by the EVSE from all charging services over a given period.

Total Cost**:** all the expenses involved in installing and maintaining the EVSE.

- ***Social Cost***

Include aspects such as impact on the local environment and equality issues [27]. The objective is to minimize social and environmental impacts of charging infrastructure development.

4.2 Correlation between KPIs and EVSE clusters

Clustering ensures KPIs are interpreted within their operational context. For example, if we measure utilisation rate without context, we think that higher is always better, but different EVSE clusters operate under different conditions. CL1 has low voltage supply and slow charging speed. Drivers often leave cars plugged in for many hours. That might be normal if utilization rate is lower. CL4 has medium/high voltage supply and fast charging speeds. Drivers stop briefly (15–30 minutes). Higher utilization rate is expected in this context.

Linking KPIs with EVSE cluster ensure an accurate benchmarking which means compare performance against targets that fit the purpose of the charger. Some chargers are designed for constant turnover (for example in highway when one car finishes charging, leaves, and another car takes its place) others are meant for occasional use (remote areas). So, each cluster should have different KPI goals.

In Table 11 we provide a link between the KPIs, stakeholder groups and EVSE clusters. Given the stakeholder group and the cluster, the table provides the KPIs that are more significant.

Table 11: Correlation between KPIs, clusters and stakeholders

ID	Name	Cluster-Stakeholder group
1	Utilisation Rate	CL4-Users, CL4-CI Market Players, CL4-Grid Operators. CL2-Users, CL2-CI Market Players, CL2-Grid Operators.
2	Charge start success	CL2-CI Market Players, CL2-Users, CL2-Grid Operators. CL4-CI Market Players, CL4-Users, CL4-Grid Operators. CL1-Users, CL1-Grid Operators.
3	Charge Start time	CL2-CI Market Players CL4- Market Players.
4	Charge end success	CL1-Users, CL1-CI Market Players CL2-Users, CL2-CI Market Players.
5	Session success	CL2-CI Market Players, CL2-Users CL4-CI Market Players, CL4-Users CL3-CI Market Players, CL3-Grid Operators
6	Location Accuracy	CL2-CI Market Players, CL2-Users CL4-CI Market Players, CL4-Users CL5-Policy Makers.

7	Wait Time	CL2-CI Market Players, CL2- Users, CL2-Grid Operators CL4-CI Market Players, CL4- Users, CL4-Grid Operators CL5-Policy Makers, CL5-Grid Operators
8	Extend Charge Time	CL4-CI Market Players, CL4 Users CL2-CI Market Players, CL2-Users.
9	First-time session success	CL1-Users CL2-Users
10	Visit success	CL2-CI Market Players, CL2-Users CL4-CI Market Players, CL4-Users
11	Utilisation Rate	CL2-CI Market Players, CL2-Grid Operators CL4-CI Market Players, CL4-Grid Operators CL3-CI Market Players, CL3-Grid Operators.
12	Market Bid Acceptance Rate	CL1-Grid Operators CL3-Grid Operators CL8-Grid Operators.
13	Cybersecurity Incident Count	CL5-CI Market Players, CL5-Grid Operators CL6-CI Market Players, CL6-CI Grid Operators CL2-CI Market Plyers
14	User Consent Rate	CL1-Users CL2-Users
15	Occupancy Rate	CL2-CI Market Players, CL2-Users CL4-CI Market Players, CL4-Users
16	Total Energy Delivered	CL1-CI Market Players, CL1-Grid Operators CL2-CI Market Players, CL2-Grid Operators CL3-CI Market Players, CL3-Grid Operators CL8-CI Market Players, CL8-Grid Operators.
17	Protocol Compliance Rate	CL2-CI Market Players, CL2-Grid Operators CL3-CI Market Players, CL3-Grid Operators CL8-CI Market Players, CL8-Grid Operators.
18	Alliance Service Delivery Rate	CL2-CI Market Players CL4-CI Market Players.

19	Bid Size Adherence	CL3- CI Market Players CL8- CI Market Players.
20	Market Transaction Volume	CL3- CI Market Players CL8- CI Market Players.
21	Cluster Voltage Compliance	CL1-Grid Operators CL3-Grid Operators CL8-Grid Operators.
22	Idle Time	CL2-CI Market Players CL4-CI Market Players CL7-CI Market Players.
23	Turnover	CL2- CI Market Players CL4- CI Market Players
24	Turnover from advertisement	CL2-CI Market Players
25	Return on Investment	CL2-CI Market Players CL3-CI Market Players CL8-CI Market Players, CL8-CI Grid Operators.
26	Peak Power	CL4-CI Market Players, CL4-Grid Operators CL8-CI Market Players, CL8-Grid Operators CL1 Grid Operators.
27	Social Cost	CL4-Policy Makers, CL4-Users CL5-Policy Makers CL6-Policy Makers
28	Unique users rate	CL2-CI Market Players, CL2-Users CL4-CI Market Players, CL4-Users
29	Flexibility Activation Efficiency	CL1-Grid Operators CL3-Grid Operators CL8-Grid Operators, CL8-CI Market Players
30	Grid Constraint Compliance Rate	CL1-Grid Operators CL3-Grid Operators CL5-Grid Operators

		CL6-Grid Operators CL8-Grid Operators
31	Cost Efficiency of EVSE Flexibility	CL1-CI Market Players, CL1-Grid Operators CL3-CI Market Players, CL3-Grid Operators CL8-CI Market Players, CL8-Grid Operators
32	Imbalance Reduction from EVSE Coordination	CL1-Grid Operators CL3-Grid Operators CL8-Grid Operators
33	Communication Latency	CL2-CI Market Players CL8-CI Market Players
34	EVSE Participation Rate	CL3-CI Market Players CL8-CI Market Players
35	Availability Factor	CL2-CI Market Players, CL2-Grid Operators CL4-CI Market Players, CL4-Grid Operators CL5-Policy Makers, CL5-Grid Operators CL6-Policy Makers, CL6-Grid Operators
36	Cost Savings from EVSE Flexibility	CL1- CI Market Players, CL1- Grid Operators CL3- CI Market Players, CL3- Grid Operators CL8- CI Market Players, CL8- Grid Operators
37	Charging Power	CL4-CI Market Players, CL4-Grid Operators CL8-CI Market Players, CL8-Grid Operators
38	Charging Efficiency	CL3-CI Market Players CL7-CI Market Players CL8-CI Market Players
39	Charging Session Duration	CL1-Users CL2- CI Market Players, CL2-Users CL4- CI Market Players, CL4-Users

4.3 Integration with decision support tools

The main interrelation of this deliverable pertains to Task 4.4 of this work package which encompasses the development of a hosting capacity spatial mapping model to support decision making. The Task 4.4 aims to create a decision-support model for planning EVSE infrastructure in cities, using validated distribution network data. It will map hosting capacity for each grid element under current conditions and with flexibility services. This information will help municipalities and public authorities understand network constraints and opportunities. Finally, this model will feed an AI tool to identify optimal EVSE deployment locations with minimal network impact.

A subset of KPIs identified in the previous section will be used to evaluate the decision-support tool's performance. These include KPIs from sections 4.1.4 and 4.1.5, which relate to EVSE flexibility and efficiency and with grid compliance. From section 4.1.4, all KPIs are applicable, and the total energy delivered, the peak power and the flexibility activation efficiency will be computed. Regarding the cost related KPIs, namely the cost efficiency of EVSE flexibility and the cost savings from EVSE flexibility, although being relevant, they may not be computed in the tool's initial stage. From section 4.1.5, three KPIs will be computed: cluster voltage compliance, grid constraint compliance rate and imbalance reduction from EVSE coordination.

To better evaluate the tool, additional KPIs tailored to hosting capacity will also be considered:

1. Maximum number of EVs that can be integrated without violating grid limits – the main KPI for a hosting capacity tool, which can be broken down by charging type (uncoordinated, coordinated and bidirectional charging).

$$N_{EV,max}^{strategy} = \max\{N_{EV}: all\ V, I, P\ within\ limits\ inder\ strategy\}$$

- $N_{EV,max}^{strategy}$: Maximum number of EVs that can be integrated without grid violations under a given charging strategy.
- N_{EV}: Number of EVs simulated under each scenario.
- V, I, P: Voltage, current, and power flow values (constrained by grid thermal and voltage limits).
- $Strategy$: Uncoordinated, coordinated, and bidirectional charging

2. Charger type – slow, fast, or super-fast.

$$Share_c = \frac{\mathrm{N_c}}{\mathrm{N_{EVSE}}} \times 100, c \in \{slow, fast, super - fast\}$$

- $Share_c$: Percentage of chargers of type c.
- $\mathrm{N_c}$: Number of chargers of type c.

- $\mathrm{N_{EVSE}}$: Total number of EVSEs.

3. Percentage of time with voltage levels outside limits – to assess grid stability under different EV penetration levels.

$$KPI_{V_{out}} = \frac{\sum_{b=1}^{N_b}\sum_{t=0}^{T}(V_b(t) < V_{min} \cup V_b(t) > V_{max})}{N_b \cdot T} \times 100$$

- $KPI_{V_{out}}$: Percentage of time voltage exceeds permissible range (%).
- $V_b(t)$: Voltage magnitude at bus b at time t (p.u.).
- V_{min}, V_{max}: Regulatory voltage limits (e.g., 0.90 – 1.10 p.u.).

4. Average transformer utilization (%) – to measure stress on network assets.

$$KPI_{SS} = \frac{1}{\mathrm{N_t}}\sum_{j=1}^{N_T}\frac{\overline{S_J}}{S_{j,rated}} \times 100$$

- KPI_{SS}: Percentage of time voltage exceeds permissible range (%).
- $\mathrm{N_t}$: Number of transformers in analysis.
- $\overline{S_J}$: Average apparent power flow through transformer j over the simulation horizon (kVA).
- $S_{j,rated}$: Rated apparent power of transformer j (kVA).

5. Number of overload or undervoltage events – to identify critical points in the network.

$$N_{events} = N_{ovl} + N_{uv}$$

- N_{events}: Total number of critical operational violations detected.
- N_{ovl}: Number of overload events where current/power > allowed limit.
- N_{uv}: Number of undervoltage events where voltage < V_{min}.

6. Peak load reduction (%) with activation of flexibility services – a KPI that shows the benefits of these services.

$$KPI_{PeakRed} = \frac{P_{peak,base} - P_{peak,flex}}{P_{peak,base}} \times 100$$

- $KPI_{PeakRed}$: Percentage reduction of maximum system peak demand through EVSE flexibility.
- $P_{peak,base}$: System peak demand without EVSE flexibility (kW).
- $P_{peak,flex}$: System peak demand with EVSE flexibility activated (kW).

These KPIs are tailored for the decision support tool and some of the formulation might be adjusted according to the task development.

5 CONCLUSIONS AND RECOMMENDATIONS

This deliverable provides and in-depth analysis of the most significant measurable indicators that define and categorize electric vehicle supply equipment (EVSE). It provides a comprehensive analysis of stakeholders interested in EVSE development, the key indicators each stakeholder is interested, and how these can be used to facilitate a multidimensional decision-making process of infrastructure expansion.

The work is focused on three main parts, namely:

- EVSE characteristic and Stakeholder interests (Chapter 2)

Here the main stakeholders interested in EVSE are defined and organized in groups based on their interests and focus area. For each group a set of key factors is analysed. The results and the findings are based on a deep literature analysis and a survey conducted on roughly 100 stakeholders. Many characteristics define EVSE, and they can be grouped in three main categories: technical, economic, and social. Technical characteristics (i.e., charging power, down time, etc.) concern with the specifications and the capabilities of the charging equipment. Grid Operators, EV Users and Market Players are mostly interested in characteristics. On the other hand, market players and users are the groups mainly interested in the economic characteristics. Indicators such as return of investment, downtime, and high operational reliability are significantly important for these stakeholders. Lastly the social impact (i.e., pollution reduction, traffic, geographical distribution, etc.) is the most factor for Policy makers and Public Utilities.

- EVSE classification framework (Chapter 3)

The enlargement of the charging network is a multi-dimensional decision where many factors play a role. Depending on the goal and the stakeholders the criteria that determine the most convenient outcome can vary significantly. In this Chapter EVSE are grouped in clusters based on their main characteristics: access, voltage level, location, and ancillary services. In addition, a selection scheme is proposed. Given the selection criteria the scheme selects the appropriate cluster and based on the cluster and the stakeholder group (i.e. the stakeholder which is interested in the new equipment), the most suitable Key Performance Indicators (KPIs) are provided.

- Key Performance Indicators (Chapter 4)

Chapter 4 presents a comprehensive list of KPIs that define the characteristics of EVSEs. First the list with the calculation formula for each KPI is provided and explained, as KPIs should be measurable and quantifiable. Here KPIs are grouped by area of interest to facilitate their readability and a link with the interested stakeholders is provided. In addition, a correlation table between the KPIs and the stakeholder group is provided. The tables serve as the final step of the selection process proposed in Figure 3.1. Finally, a subset of KPIs is selected. These are KPIs related to the distribution grid management and will be used in Task 4.4 to evaluate a decision-support tool performance.

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APPENDIX A

EV CHARGING STAKEHOLDER SURVEY: IDENTIFYING PRIMARY NEEDS

Section 1: Respondent Information

1. Please select the stakeholder type you represent (select one or more):

INDUSTRY

- ☐ Tech provider/ Manufacturer
  - OEM
  - EVSE manufacturer
- ☐ System operator
  - TSO
  - DSO
  - Aggregator (VPP operator, flexibility operator)
  - Energy company

SERVICES

- ☐ CPO
- ☐ eMSP
- ☐ EV Fleet Manager
- ☐ IT

POLICY

- ☐ Policymaker
  - EU
  - National
  - Regional
  - Local
- ☐ Regulatory Authority
- ☐ International organisation
- ☐ National ministry
- ☐ Municipality
- ☐ Think tank

END USERS

- ☐ EV owners & associations
- ☐ Vehicle operators
- ☐ Energy community
- ☐ Collective consumers
- ☐ Indirect end users (tourists)

2. Geographic focus of your activities (if relevant):

- ☐ Local
- ☐ Regional
- ☐ National
- ☐ European
- ☐ International

Section 2: Relevance of Needs

Please indicate the importance of each of the following needs as your indicated stakeholder type. Use a scale from 1 (Not Important) to 5 (Very Important).

A. Charging Infrastructure Coverage & Accessibility

Ensuring broad geographic coverage
☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5
Accessibility in rural/underserved areas
☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5
Real-time information on station availability
☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5
OTHER:
☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5

B. Charging Speed & Reliability

Availability of fast/ultra-fast chargers
☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5
Minimal downtime and high operational reliability
☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5
Short wait times at stations
☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5
OTHER:
☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5

C. Economic and Market Considerations

Affordability of charging for users
☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5
High utilization and ROI for operators
☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5
Fair and transparent pricing models
☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5
OTHER:
☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5

D. Sustainability and Grid Integration

Use of renewable energy for charging
☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5
Grid stability and peak demand management
☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5
Support for smart charging / V2G
☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5
OTHER:
☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5

E. User Experience and Innovation

Ease of use (apps, payment, UI)
☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5
Availability of station amenities
☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5

Technology innovation and standardization
☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5
OTHER:
☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5

Section 3: Top Priorities

From the list selection, what would you consider the top 3 needs (ranked in order of importance).

A. Charging Infrastructure Coverage & Accessibility
B. Charging Speed & Reliability
C. Economic and Market Considerations
D. Sustainability and Grid Integration
E. User Experience and Innovation
F. Other (please specify)

1. ________________________________
2. ________________________________
3. ________________________________

Section 4: Respondent Information – EV Drivers Relevance of Needs

Are you a driver/user of electric vehicles?

☐ Yes
☐ No

If yes, please indicate the importance of each of the following needs as an EV driver. Use a scale from 1 (Not Important) to 5 (Very Important).

A. Charging Infrastructure Coverage & Accessibility

Ensuring broad geographic coverage
☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5
Accessibility in rural/underserved areas
☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5
Real-time information on station availability
☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5
OTHER:
☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5

B. Charging Speed & Reliability

Availability of fast/ultra-fast chargers
☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5
Minimal downtime and high operational reliability
☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5
Short wait times at stations
☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5
OTHER:
☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5

C. Economic and Market Considerations

Affordability of charging for users
☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5
High utilization and ROI for operators
☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5
Fair and transparent pricing models
☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5
OTHER:
☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5

D. Sustainability and Grid Integration

Use of renewable energy for charging
☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5
Grid stability and peak demand management
☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5
Support for smart charging / V2G
☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5
OTHER:
☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5

E. User Experience and Innovation

Ease of use (apps, payment, UI)
☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5
Availability of station amenities
☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5
Technology innovation and standardization
☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5
OTHER:
☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5

Section 5: Top Priorities

From the list selection, what would you consider the top 3 needs as an EV driver (ranked in order of importance).

A. Charging Infrastructure Coverage & Accessibility
B. Charging Speed & Reliability
C. Economic and Market Considerations
D. Sustainability and Grid Integration
E. User Experience and Innovation
F. Other (if provided)

1. ________________________________
2. ________________________________
3. ________________________________

Section 6: Additional Comments

Do you have any additional needs, suggestions, or concerns regarding EVSE infrastructure?