Review

Planning and Operation Objectives of Public Electric Vehicle Charging Infrastructures: A Review

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Abstract: Planning public electric vehicle (EV) charging infrastructure has gradually become a key factor in the electrification of mobility and decarbonization of the transport sector. In order to achieve a high level of electrification in mobility, in recent years, different studies have been presented, proposing novel practices and methodologies for the planning and operation of electric vehicles charging infrastructure. In this paper, the authors present an up-to-date analysis of the existing literature in this research field, organized by considering the perspectives and objectives of the principal actors/operators of the EV public charging infrastructure value chain. Among these actors, the electric vehicle, the charging operators and service providers, and the power system infrastructure (transmission and distribution system) are analyzed in depth. By classifying the reviewed literature based on this manifold viewpoints approach, this paper aims to facilitate researchers and technology developers in exploring the state-of-the-art methodologies for each actor's perspective, and identify conflicting interests and synergies in charging infrastructure operation and planning.

Keywords: public charging infrastructure planning; electric vehicles; charging station operator; mobility service operator; power system network; distribution system operator; transmission system operator; flexibility options

1. Introduction

Recently, electric vehicles (EVs) are becoming a potential substitution for internal combustion engine vehicles (ICEVs) in transportation and mobility [1–3]. EVs require access to charging points and the type and location of the chargers are not entirely the choices of the vehicle owners [1]. Government and electric utility companies' policies, as well as techno-economical advances and barriers, have a decisive impact in the pace of EV charging infrastructure building [1–3]. Depending on EV inventory, travel patterns, transportation modes, and urbanization trends, the location, distribution, and type of electric vehicle recharging facilities can differ by region and time [1]. The installation of public chargers has increased seven-fold in the years 2015–2020 [1]. While most EV charging is conducted at home and at workplaces, the deployment of public charging points will be critical as countries leading EV deployment are entering a stage wherein EV owners will demand higher autonomy and simplicity [1–3]. European countries, for the most part, have not met the electrical vehicle supply equipment (EVSE) targets recommended for public charging points set by the Alternative Fuels Infrastructure Directive (AFID) [1]. However, the success of electric vehicles is due to multiple factors, such as the ongoing decrease in battery costs, the increased availability of electric car models as well as public charging stations, and the acceptance of EVs by fleet operators, also complemented by local policy measures [1–3]. Sustained political support is one of the main pillars of electromobility [2]. Therefore, European Union (EU) policies, programs, and initiatives that support synergies between the transport and energy

sectors are needed to encourage the end-user to move toward more sustainable mobility, such as EVs.

Regarding the policies for mobility, the EU has set targets to become carbon neutral by 2050 and achieve a 55% reduction on the 1990 emissions by 2030 [1–3]. To achieve these goals, passenger cars and vans (light commercial vehicles), which today account for about 12% and 2.5% of total EU CO_2 emissions, must be decarbonized urgently [1–3]. Actions should be taken to boost the deployment of zero-emission vehicles, as vehicles launched from the mid-2030s are expected to remain on the road until 2050 [1,2,4]. By 2022, global sales of electric cars will have increased at a significant rate. With this increase in sales of zero-emission vehicles, nearly 10% of global car sales were electric in 2021, four times the market share in 2019 [2].

Thereby, the charging infrastructure of EVs is typically analyzed with different approaches considering different parameters: type of vehicles, localization, cost of the grid infrastructure, etc. The authors of [5–14] mainly theorize that the electrification of heavy traffic of the road transport sector could be achieved through the use of static charging, an electric road system (ERS), and electricity to produce a fuel (such as hydrogen or synthetic hydrocarbons) for on-board use in internal combustion engines [15].

The approach of this review consists of an analysis of the available literature on the planning and operation of public charging infrastructure for EVs based on a proposed value chain taking into account various actors in the system which may intervene. The value chain presented here is mainly structured according to the key players who are involved in the energy supply flow, which involves from electric vehicle environment to the power system infrastructure including distribution and transmission networks, through the infrastructure and maintenance of charging stations. Without going into the details of the methodology, this paper aims to outline the different actors and operators involved in the public planning of EV charging points, who they are, and what objectives or aspects they mainly focus on in order to carry out this planning. The main contribution of the approach presented compared to existing ones, e.g., Unterluggauer et al. [10], is how the chain is divided into different actors/operators and the consideration of the mobility service operator (MSO) as an operator in the EV infrastructure value chain. This paper considers this operator as necessary for a holistic analysis and to be considered in the value chain for its influence of mobility services provided to the end-user and the charging point operator (CPO) regarding user comfort and energy management on the whole value chain. Ahmad et al. [9] covers concepts, objective functions, constraints, modeling loads, uncertainties, vehicle-grid strategies, distributed generation integration, charging modes, optimization techniques, and sensitivity analysis, and discusses optimization techniques for the optimal solution but does not consider the behavior or needs of the customer who would purchase and use the vehicle. Other studies, such as Hardman et al. [7], address the literature on consumer preferences for charging infrastructure and consumer interaction with and use of that infrastructure.

This review paper is organized as follows (Figure 1): Section 2 introduces the value chain considering the different actors in the system that can interfere with a brief description of each of them. Thus, it gives an overview of the main concepts presented in this approach. Section 3 describes what is considered an agent and an operator in the presented value chain related to the charging infrastructure ecosystem. Therefore, it describes for each agent and operator the different actors that may be involved, as well as a description of what objectives they may pursue typically included in the different studies analyzed. The particular objective of the different agents and operators that may intervene in the EV charging infrastructure value chain, which may vary according to the particular requirements of the operation or planning, are described in Section 4. Finally, Section 5 summarizes the electric vehicle charging infrastructure ecosystem, identifying and analyzing the main research findings.
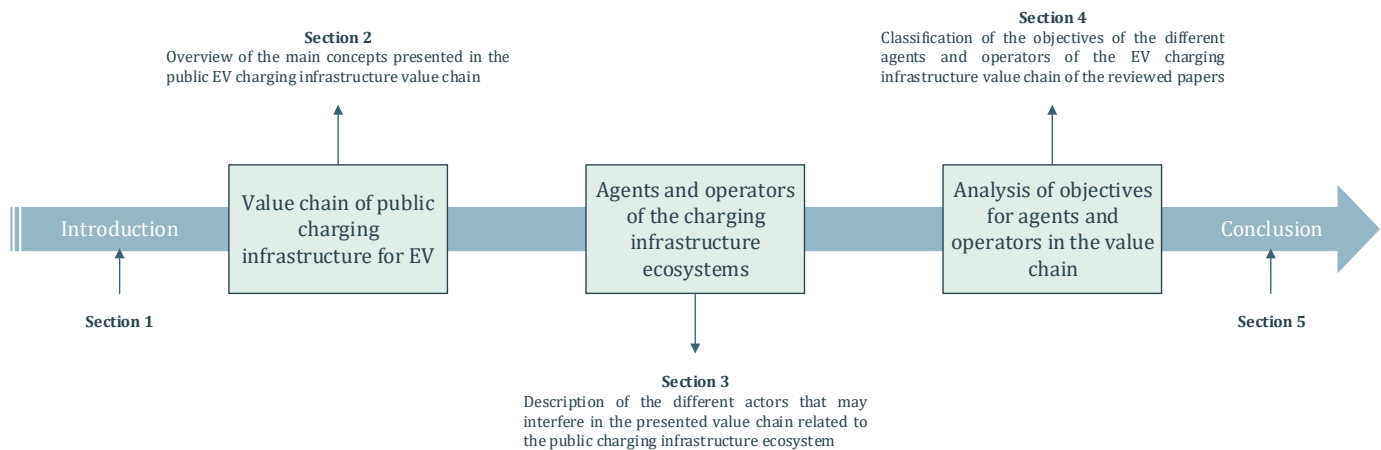
Figure 1. Structure of the review paper.

2. Public EV Charging Infrastructure Value Chain

This paper analyzes the literature available for the planning and operation of public charging infrastructure for electric vehicles based on a proposed value chain considering the different actors that interact in the system. This value chain is divided into the main actors intervening in the energy supply flow. Starting with the electric vehicle, followed by the infrastructure and service of charging stations, and finally, the power system infrastructure wherein the distribution system and the transmission system are responsible for providing electrical supply to the local electrical substation and to the regional or national electrical substation, respectively.

The identified actors involved in the EV charging infrastructure are described here as agents or operators. Considering the power system infrastructure and, more specifically, in the electricity market environment, an agent can be defined as any individual or legal entity that is involved in economic transactions that occur in the electric power market by purchasing or selling electric power, such as producers of electricity, retailers, and direct consumers on the market [16]. Additionally, like the transmission system, the distribution system, or the electricity market, an operator can be viewed as a system manager of a complex system. As part of the overall energy system, operators typically have legally defined functions and obligations. For instance, the market operator acts as a neutral party between buyers and sellers, accepting bids to purchase and sell energy and settling the results of matching processes in the day-ahead and intraday markets [16].

Concerning the charging infrastructure ecosystem, the value chain is differentiated into three blocks of the different agents and operators, as it is described in Figure 2: Electric vehicle ecosystem, EV charging infrastructure, and service and power system infrastructure.On the one hand, is considered an agent any individual who uses a vehicle, such as the EV car end-user, i.e., the driver, regarding the electric vehicle ecosystem. On the other hand, an operator is described as any system manager that interferes in the value chain by providing services to the EV. On the second block is presented the EV charging infrastructure and service; it is included the CPO, which takes care of operating the charging stations, or the MSO, which provides information about the location of the charging stations, managing the energy consumption and the cost of the charge, etc., to increase the user comfort of the EV agent. Finally, in the power system infrastructure block, the distribution system operator (DSO) and the transmission system operator (TSO) manage the electricity supply from the grid to the charging point at the local and national levels, respectively.
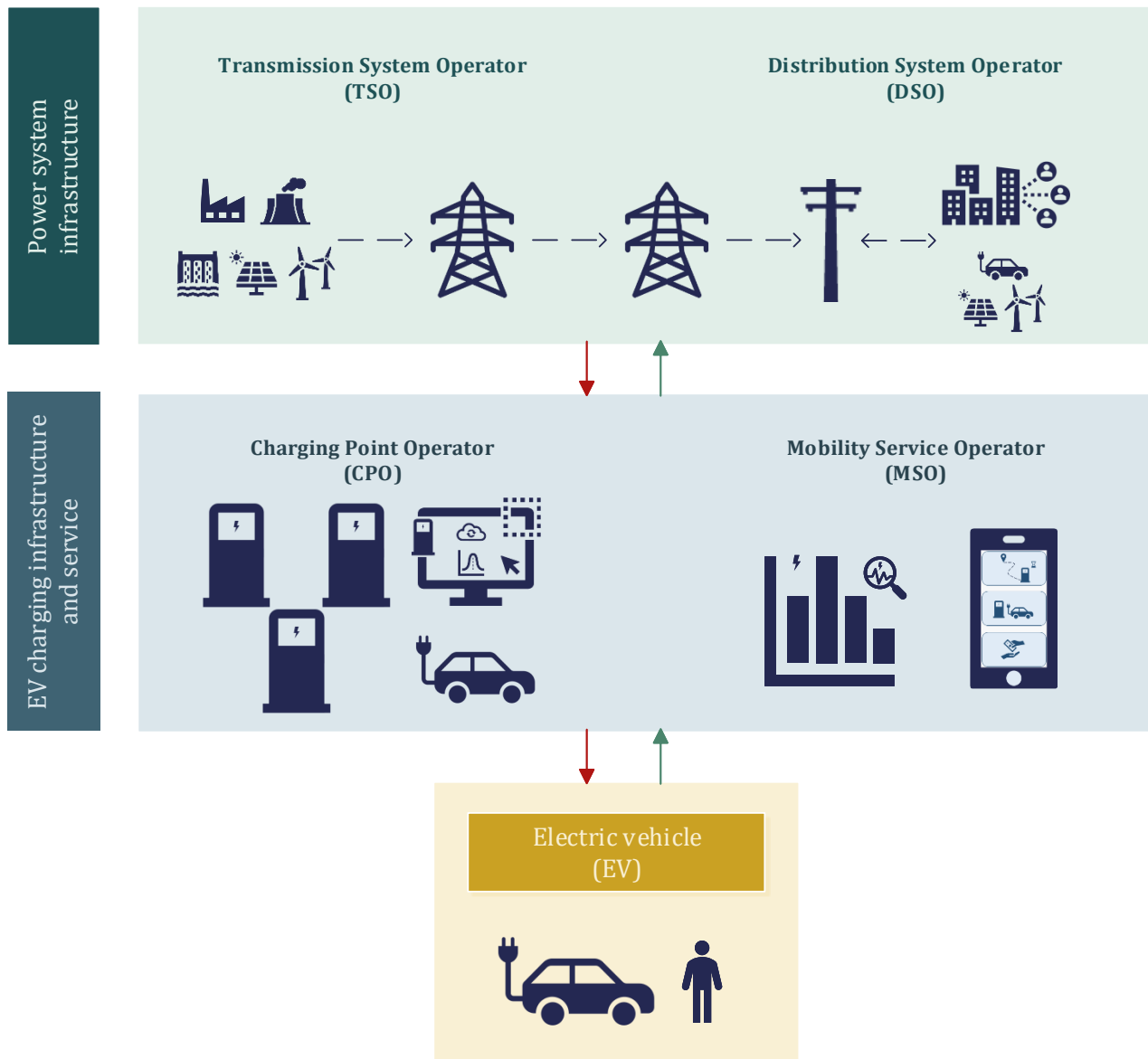
Figure 2. Charging infrastructure value chain.

- **Electric vehicle**: This block encompasses both the electric vehicle and its environment, including the vehicle's technical features and the user of the vehicle. Thus, the user may not necessarily be the owner of the electric vehicle, including new forms of mobility, such as car-sharing and company fleets that have emerged. The role of the vehicle owner could be evolving into that of the end-user, who utilizes the technology but does not necessarily own it. The driver of a vehicle is adapting to these new mobility models.

  – EV ecosystem: the actors involved with the EV considering not only the technical characteristics of the vehicle but also the possible concerns of the vehicle's user.

- **EV charging infrastructure and service**: this group encompasses the electric vehicle charging infrastructure, from the installation of the charging equipment by the CPO to the management of the services provided by the MSO. These two differentiated actors, CPO and MSO, who may be part of the same company, are responsible for distinct tasks. The CPO is responsible for the implementation of the charging infrastructure,

taking into consideration technical and financial aspects. The MSO, on the other hand, manages the operation of the service and facilitates its usage for the end-user.

- Charging Point Operator (CPO): electric utilities and specialized service companies, primarily those fast charger installers, which set up and maintain public charging stations. This category also includes the design and manufacture of charging hardware, such as pedestals, sockets, and charging cables.
- Mobility Service Operator (MSO): provides charging and different mobility services to end-users for public charging points. These services can consist of maps of charging points, billing mechanisms, and roaming services that allow the end-user to recharge using different charging networks.

- **Power system infrastructure**: this block covers electricity system operators, including those responsible for managing the electricity grid at the local level (DSO) and at the regional or national level (TSO). Both DSOs and TSOs have similar objectives of ensuring grid stability at a lower cost. The primary difference between them lies in their power transfer capability and distances. The transmission system is typically a highly interconnected system designed for transferring large amounts of electricity from generators to consumption points.

- Distribution System Operator (DSO): distributes electricity from the transmission grid substations to the final-end consumers, which in this case are the charging points.
- Transmission System Operator (TSO): transmits electrical power from bulk generation plants over the electrical transmission grid to a transmission substation, where the distribution grid is supplied.

These defined roles in the charging infrastructure ecosystem define categories that have specific interests: user-centered (EV), infrastructure- and service-centered (CPO and MSO), and power system-centered (DSO and TSO). Each of the actors listed briefly above are described in detail in the following subsections.

Main Trends and Good Practices

The planning of public charging infrastructure for EVs is crucial for the widespread adoption of EVs and the transition to a sustainable transport system. This section highlights the methodologies and findings of various studies and provides an overview of good practices and main trends in the field. It aims to provide valuable information to stakeholders involved in planning and implementing public EV charging infrastructure.

Predicting carbon emissions [15,17], heuristic approaches to locating the charging stations considering technical and economic barriers [18–24], understanding consumer preferences [7,8,20], and socio-technical energy transitions [2,9,10,12,25–28] can be significant factors in the planning of public EV charging infrastructure. Stakeholders can develop effective strategies to facilitate the widespread adoption of electric vehicles and contribute to sustainable transportation.

Thus, the integration of EVs into the smart grid using vehicle-to-grid (V2G) technology is an important aspect of planning public EV charging infrastructure. For example, ur Rehman [25] propose an optimal algorithm that optimizes EV charging/discharging, predicts power demand, and utilizes EVs and charging stations for voltage and frequency stabilization.

Another important trend is the economic value of EV grid integration. Wu and Lin [18] suggest that controlled charging without V2G can smooth the load curve and reduce electricity supply costs. They suggest that EVs should be allowed to participate in the electricity market as a source of electricity, resulting in optimal revenue generation for the grid.

Furthermore, a comprehensive evaluation of EV charging infrastructure is essential for stable development. For example, He et al. [20] develop an evaluation system and method that analyzes the coupling relationship among users, charging infrastructure, road network, and power grid by proposing evaluation criteria and indices to evaluate the impact on

various topics, which provides a reference basis for the planning and improvement of EV charging station networks.

The efficient planning of charging infrastructure is critical for widespread EV adoption. Liu [19] propose a two-stage planning model that accounts for uncertain factors and constraints, with the goal of maximizing revenue and minimizing charging costs. In addition, Unterluggauer et al. [10] highlight the need for integrated modeling approaches and detailed charging demand analysis, emphasizing the importance of considering different types of charging options. Addressing these issues will allow decision-makers to ensure the effective deployment of charging infrastructure to support the growing EV market.

Section 3 provides a more exhaustive analysis of the trends and studies that are being carried out, differentiating between each of the actors and operators presented in Figure 2.

3. Agents and Operators of the Charging Infrastructure Ecosystems

In Section 2, the main actors identified in the proposed charging infrastructure value chain have been introduced and briefly discussed, as seen in Figure 3. In this section, each actor is described in detail, providing the main references for an in-depth analysis of the actor's perspectives in the interaction with the charging infrastructure ecosystem.
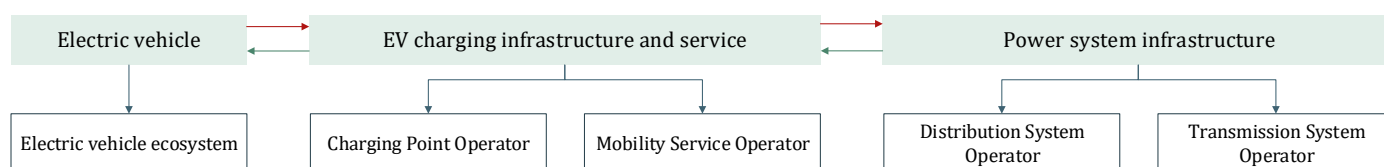

Figure 3. Charging infrastructure value chain scheme.

The papers presented are finally organized in a systematic classification in Section 4, where the main actors' operational and planning objectives are identified and discussed.

3.1. Electric Vehicle

The electric vehicle ecosystem has undergone recent transformations due to the emergence of new technologies and vehicle designs, requiring users to adjust to these changes. Thus, the automotive fleet is one of the most relevant element to consider when planning charging stations for EVs. Different types of vehicles use one or more electric motors for propulsion. Regarding that, vehicles can be divided according to weight into different categories: light duty vehicles (LDVs) and heavy duty vehicles (HDVs) [5]. Moreover, according to their electrification level, EVs can be divided between battery electric vehicles (BEVs) and plug-in hybrid electric vehicles (PHEVs).

Table 1 summarizes the different electric vehicle characteristics considering the type of electrification and vehicle analysis. Although the sizing of the battery is out of the scope of this paper, it has to be considered in order to analyze the range anxiety that the user of the vehicle can suffer.

Table 1. Average fleet specification classified by types of EVs [5,15,27,29–32].

Vehicle	Peak Power (kW)	Size of the Battery (kWh)	Energy Consumption (kWh/km)
PHEV—Passenger cars	20	24	0.2
BEV—Passenger cars	80	70	0.2
Buses	300	500	1.2
Light trucks (i.e., vans, distribution trucks)	120	340	1
Heavy trucks	300	480	2

Reference [8] studies an integrated framework for urban fast-charging infrastructure to address the range anxiety issue. Moreover, there are different studies analyzing user

perspectives. For example, Hardman et al. [7] presents a review of various studies examining infrastructure needs related to consumer preferences for charging infrastructure, and user responses and usage. Study Venegas [33] analyzes EV integration into distribution systems through technical, behavioral, economic, and regulatory aspects. The correlation between charging stations and user behavior, based on their travel route, is investigated in [34,35]. Shahraki et al. [34] designs an optimization model based on vehicle driving patterns to identify public charging demand and locate public charging points to maximize electrified vehicle-miles-traveled (VMT). In the work of Zang et al. [35] first, a travel pattern model based on Monte Carlo Simulation (MCS) was developed, and then a bi-level charging infrastructure planning model was designed using EV travel data.

The papers [7,8,20] perform an analysis also considering the user behavior. Using information from questionnaires, interviews, modeling, vehicle GPS data, and electric vehicle charging equipment data, Hardman et al. [7] present a literature review of studies that have examined the infrastructure requirements to implement plug-in electric vehicless (PEVs) in the marketplace, focusing on the literature on consumer preferences for charging infrastructure and how consumers interact with and use this infrastructure. While in Kavianipour et al. [8], using a simulation tool designed to model trip trajectories and simulate charging behavior based on various trip parameters, an integrated framework for urban fast-charging infrastructure is presented to address the issue of range anxiety. Moreover, under the coupling of road network and electric power system, a comprehensive system and evaluation method for EV charging networks is presented in He et al. [20], where an EV displacement model is developed based on the displacement probability matrix to analyze the spatial and temporal characteristics of EVs, by studying the coupling relationship among users, charging network, road network, and electric power system.

Electric Vehicle Ecosystem

Once the different EV configurations have been analyzed, the existing charging technologies are also examined through the literature available, which could affect the end-user. The electrification of the vehicle fleet typically considers multiple scenarios and technologies [4,15]. Moreover, user behavior should also be considered when analyzing the impact of mobility electrification [7,20,33–35]. The following is a description of the technologies involved and the various electric vehicle charging solutions that the user has had to deal with.

- **One-Way Charging** describes the straightforward operation where a charging point is directly connected to the grid and receives power when plugged in. It has the disadvantage of not controlling the charging of the vehicle, which can lead to an undesirable charging pattern (i.e., when electricity prices are high due to high demand and could significantly increase the utility bill of the operator managing this solution) [36,37].
- **Smart charging** enables users to schedule charging. It can actively vary the charge rate (the amount of energy consumed from the grid at any given time) and is typically used to charge when tariffs are low. This charging option can help save on electricity costs and reduce the EV's load on the grid when plugged in for charging. Charging station integration with energy management software is required for this charging option [36–38].
- **Bidirectional Charging (V2X)** includes Smart charging characteristics and enables EV batteries to store and discharge energy back and forth to and from the building/home/grid.
  This technology allows EVs to become portable energy storage units for renewable sources such as solar and wind, which are variable. Bidirectional charging can also include V2G, vehicle-to-building (V2B), or vehicle-to-home (V2H) [23,38,39] which allows for excess stored energy from an EV battery to be injected back into a building or home. In addition to reducing the cost of charging, it also helps to save on a building's utility bills because the EV is providing a portion of the facility's energy needs [39]. This configuration is most cost-effective when the vehicle charging infras-

tructure is connected to the same utility meters as the facility [36,37]. Furthermore, it can support critical loads of buildings such as data servers, computers, emergency lights, water pumps, elevators, etc. [23,38,39]. In power supply emergencies such as power failures, the resilience of the building and the entire grid system can be increased [39]. Thus, generating flexibility without affecting the standard functionality of any building or house could be possible by applying V2B strategy [23,36–39]. Bidirectional charging (V2X) solutions, therefore, emerge as valuable off-grid investment alternatives, confirming their role as an effective means of hedging against long-term uncertainties [23].

Regarding the different bidirectional charging technologies (V2G/V2B/V2H/V2X), V2G deserves special attention due to the fact that public charging points are typically connected to public grids. V2G describes the case when an EV is used as a storage system that can give power back to the grid. Thus, it can also supply energy in return to the grid in peak hours and could contribute, for example, in fulfilling the peak energy demands as the peaking plants [18,21,23,25,26,36–44].

Generally, V2G operation requires charging stations with some control and protection functions (mode three for alternating current (AC) or mode four for direct current (DC) charging, according to IEC 61851-1 standard) [38]. Thus, this operation is carried out by using the pre-installed inverters in the EVs when parked at the charging booths or through purposely installed mega chargers equipped with high-rated inverters [25,38]. Moreover, it can also be considered a distributed energy resource, as a fleet of a few advanced EVs can provide backup power to the grid in megawatts (MW) [25]. In the literature, several algorithms are proposed with the motivation to implement the V2G technology practically. There are certain scenarios that demonstrate that it is possible to use modern EVs to help stabilize the grid through the deployment of the V2G system [25]. However, still, the practical implementation of V2G technology is absent [18,25]. Battery degradation may be a significant barrier to V2G-based services, as the additional battery cycling caused by V2G could reduce the lifetime of the battery [38]. Moreover, coupling the deployment of V2G, V2H, and V2B could be one of the policies to increase the number of EVs, provide a more efficient interconnection between energy generation and consumption, decrease peak demand, and increase global energy efficiency [39]. From an economic point of view, Luo et al. [41] proved that the prospects of bi-directional use of EVs are challenged by the high investment and Operations and Maintenance (O&M) costs of bi-directional charging stations and the strength of future distribution systems, although allocation schemes in a bi-directional V2G environment are, in most scenarios, more cost-effective than those in a uni-directional V2G environment.

In addition to everything that is discussed above, several V2G software platforms are able to combine (or aggregate) the energy from multiple EVs to create virtual power plants (VPPs). For example, these VPPs can take the excess stored kilowatts (kWs) one at a time and aggregate all of that energy into MWs that provide grid services and can even sell energy back to the grid to generate revenue [36,37].

Finally, although fuel cell electric vehicles (FCEVs) are out of the scope in this paper, fuel cell vehicle-to-grid (FCV2G) systems with large-scale buildings can have good economic benefits and high development potential [45].

3.2. Charging Infrastructure and Service

This section presents the currently emerging ERS technologies. ERS technologies can be categorized according to the type of energy transfer and placement relative to the road [5,30,31,46]. Therefore, six different groups can be identified: overhead conductive, road-bound conductive, road-bound inductive, road-bound capacitive, and road-side conductive [5,30,31,46]. Figure 4 presents a summary of those technologies followed by a description of them.
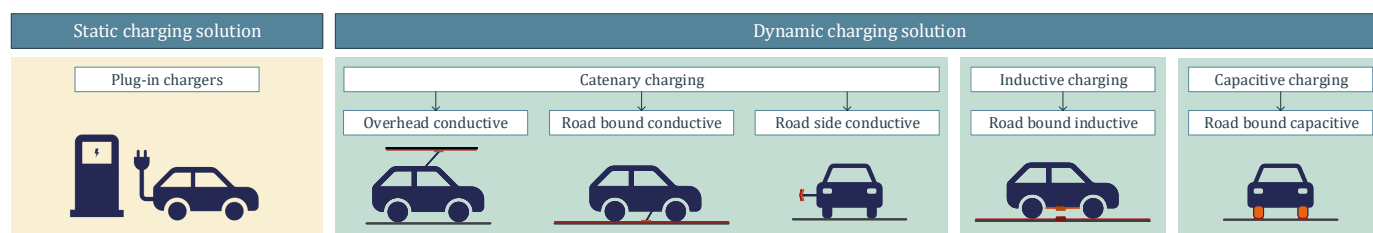
Static charging solution	Dynamic charging solution				
Plug-in chargers	Catenary charging			Inductive charging	Capacitive charging
	Overhead conductive	Road bound conductive	Road side conductive	Road bound inductive	Road bound capacitive

Figure 4. Diagram of existing charging technologies for EV.

- Plug-in chargers: it is widely recognized that slow chargers, mainly intended for private use, and fast chargers are the most prevalent types of EV chargers today [2,4,37,47]. Fast chargers are designed to reduce the charging time for EVs and have a rated power range from 150 to 400 kW. There is also specialized fast charging technology for high-power EVs on highways that can connect directly to the medium-voltage (MV) grid [5,46,48].
- Overhead conductive or catenary charging: consists of two supply lines that are installed at a height of approximately 5 meter (m) above the pavement for electric roads, where the vehicle must be supplied with a connector similar to a current collector or a pantograph to connect it to the power supply lines [30,31,46,48].
- Road-bound conductive: defined by having power conductors located close to the vehicle from the road surface. The electrical connection between the electric vehicle and the charging solution is established underneath the vehicle [30,31,46].
- Road-side conductive: composed by the power conductors placed on the side of the road, keeping the road surface unchanged. Thus, this infrastructure could have lower maintenance and installation cost [46].
- Road-bound inductive: the energy of the charging solution is transmitted from the road to the vehicle without the need for a conductive connection by using two sets of coils, primary (installed on the road) and secondary (installed under the vehicle) [5,31,46,48].
- Road-bound capacitive: is characterized by the transfer of high-frequency power from the road to the vehicle through capacitive coupling between metal plates on the road and the vehicle [46].

The choice of location and the type of charging station could be a challenge for the industry. To choose which is the most suitable solution, different parameters must be taken into account: location, estimated use, type of vehicle, and traffic patterns, among others [5–14].

Regarding this choice of charging station location, Liu et al. [14] presents a scientific approach for designing and implementing electric vehicle charging stations. They consider various factors affecting the placement of charging stations, customer satisfaction, and integration of renewable energy sources. Based on their analysis, they provide recommendations for advancing the widespread adoption of EVs and improving charging infrastructure. These suggestions include technology standards, financial incentives, land use assistance, and energy management. Zhang et al. [11] addresses the problem of finding optimal locations for electric vehicle charging stations. It reviews recent research on the topic and identifies existing problems, focusing on both algorithms and models used to find optimal locations. The study also provides an overview of traditional facility location problems and analyzes models and algorithms used specifically for electric vehicle charging station locations. Moreover, in the work of Danese et al. [5], when planning electric vehicle charging infrastructure, the authors assessed various aspects and factors, such as transport networks, modes of transport, charging technologies, and data sources and processing, followed by data types sources and data processing, to modeling, allocation, and sizing methodologies. The goal of this analysis is to provide a decision support tool for planning high-power electric vehicle charging infrastructure.

Moreover, optimal planning charging infrastructure is proposed through a bi-level problem in [6]. The authors have established a planning model for electric vehicle charging stations with a focus on balancing the costs and benefits from multiple stakeholders in the value chain. The model takes into account factors such as traffic flow, construction costs, operating costs, user time costs, and road losses. The aim of the model is to minimize the difference between the total costs and benefits of the charging station and its users.

The study conducted by Zhao et al. [49] covers different constraints regarding EV charging infrastructure considering that public charging station capacity planning is an essential factor for enabling widespread EV market penetration. Therefore, an optimization model for charging station capacity planning is presented to maximize the Fuzzy Quality of Service (FQoS) based on queuing behavior, blocking reliability, and multiple charging options grouped according to battery technical specifications.

The authors of [9,10] have presented literature reviews focusing on the optimal planning of charging stations and highlight the requirement of coordination between planning activities in the transmission and power distribution network following different types of approaches, objective functions, and constraints.

The literature analyzed in the work of LaMonaca and Ryan [12] examines the electric vehicle charging infrastructure market, covering the available charging modes, the key functions and players in the market, and the future policies needed for large-scale deployment. Thus, this research highlights the need for further transparency in pricing structures for electric vehicle charging services to improve the customer experience. It also points to the need for continued support for charging infrastructure through public–private partnerships and subsidies, and suggests that data on public charger usage be made more accessible to support future planning.

Alvarez Guerrero et al. [13] have studied the potential impact of combining electric vehicles and renewable energy sources on power system operations. Thus, they have integrated EVs and renewable energies into a production cost model with 5 min resolution and multiple planning horizons to assess the impact of variable generation and EV charging on operating costs, EV charging costs, energy dispatch, reserves, and renewable curtailment.

In addition, part of the EV charging infrastructure value chain is the service, i.e., the energy management, operated by the mobility service operator (MSO). This service consists of a software infrastructure, typically developed to provide a range of functionalities to EV users, including locating charging stations on a map with a navigation system, integrating monitoring and remote diagnostics of the charging network, performing payment processes and billing, and managing energy consumption, which may also involve the consumer interface, often based on applications such as EV charger booking services. As with any software service, the corresponding business model involves substantial initial platform development costs [47,50].

The market for mobility services is currently fragmented, highly competitive, and has great potential. Specialized start-ups are fighting for key contracts [47]. Compatibility with a wide variety of charging and vehicle hardware is critical for mixed hardware and multi-brand vehicle environments [47,51]. Given the complexity of providing multi-country coverage and the requirement to be hardware-neutral, equipment suppliers and CPOs have difficulties developing their own service platforms. In this case, specialized software companies can develop custom software to meet the needs of different customer sectors [47,52,53]. Therefore, it is necessary to offer advanced algorithms (such as self-repairing techniques for charging problems), broad functionality, user-friendliness, and reliable service [47].

3.2.1. Charging Station Operator (CPO)

The CPO can be described as a medium to large-scale electrical service provider and specialized service company for charging station installations, typically for fast chargers [47]. The CPO can manage the installation, operation, and maintenance of public charge

points [47,50]. These CPOs typically manage different charging technologies; as presented in Figure 4, the leading technologies considered in this paper are plug-in charging, catenary charging, inductive charging, and Battery Swapping Station (BSS) [5,30,31,46,54].

Plug-in chargers are typically characterized by the power output and its type. Depending on the output power, there are various commercially available modes. Mode 1 (up to 3.7 kW) and Mode 2 (up to 22 kW) operate on AC, while Mode 3 can either use AC or DC [5]. Mode 3 chargers are considered fast chargers, and the power levels can range from up to 43.5 kW for AC 3-phase technology to up to 400 kW for DC [5,46,48]. Standards are being developed for high-power chargers up to 600 kW, Mode 4, with an increasing interest in what are referred to as mega-chargers up to 1 MW HDVs [5,27].

In addition, Erdogan et al. [55] have introduced a comprehensive approach for determining the optimal configuration of electric vehicle charging stations in workplace settings. The approach results in the most efficient solution for a given workplace by combining multi-objective optimization with multi-criteria decision-making. The Pareto frontier is used to evaluate the results and determine the best option, which was found to be a DC fast charger or Mode 4, whereas the least favorable option was found to be a AC Level 2 charger or Mode 3.

The International Electrotechnical Commission (IEC) and International Organization for Standardization (ISO) are harmonizing international standards [5,27]. ISO regulates electric shock safety, battery systems, fuel efficiency measurement, and communication compatibility between the vehicle and the power grid, whereas IEC is responsible for standardizing electrical components such as batteries and charging connectors [27]. For example, in TC22 SC37, ISO provides EV standards, while ISO TC22 SC32 addresses regulations for certain equipment, such as batteries [27]. Moreover, ISO 6469, from parts 1 to 4, defines the vehicle's characteristics and main components. Furthermore, lithium battery performance for EVs, currently used in most EVs, is regulated by ISO 21405-x and IEC 62660-x, and charging system safety is addressed in ISO 1740. [27], while IEC TS 62840-1 provides a general overview of battery swap systems [5,27].

Whereas the major IEC standards related to the EV charging system mainly consist of regulations for the charging interface that connects the vehicle to an external power supply, standards related to the charging devices, and the communication between the vehicle and the external device, are also relevant to the EV charging system [5,27]. These could be summarized in IEC 61851-21-1 and IEC 61851-24, which define the requirements for the conductive connection of an EV to an AC or DC supply, and the digital communication between a DC charging station and an EV, respectively [5,27]. In addition, IEC 62196, parts 1–3, provides an interface overview of the EV and charging stations, enhances designs with a detailed definition of plugs and sockets for the AC EVs and describes the DC vehicle connector and defines the specifications of the DC vehicle connector [5,27].

Catenary charging is a method of charging electric vehicles on electric roads by using two supply lines that are placed above the road at a height of about 5 m, requiring the vehicle to use a connecting device that resembles a pantograph to establish contact with the supply lines [5,30,31,46,48]. Different studies that have analyzed this technology [30,31,46,48,56,57] generally acknowledge that catenary charging is mainly feasible for powering HDVs such as buses and trucks since it is infeasible to install the connection device in smaller vehicles. In addition, long stretches of more than 1 kilometer (km) can be electrified simultaneously, given that the catenary is difficult for humans or animals to unintentionally reach [46]. This technology is being evaluated on public roads in Sweden, where a 2 km stretch of highway is equipped with 650–750 V DC overhead power lines to which plug-in hybrid trucks equipped with pantographs are connected to run in full electric mode [46]. In the work of Marquez-Fernandez et al. [30], ERSs are analyzed as a feasible solution for electrifying heavy-duty traffic, where if only heavy transport were to be electrified, an overhead ERS solution would be competitive compared to the conventional fossil-fuel alternative. In the work of Gustavsson and Hacker [57] is provided an overview of the concepts of ERSs and complementary technologies.

For this purpose, Siemens has developed a technology called eHighway for overhead contact lines, which was evaluated on a 2 km test section east of Berlin (Germany) and also demonstrated by the South Coast Air Quality Management District in 2017 together with three different trucks along a mile of urban road in Los Angeles County, USA.

Inductive charging is a technology that transfers charging solution energy from the road to the vehicle without requiring a conductive connection. It uses two sets of coils, the primary (installed on the road) and the secondary (installed under the vehicle) [5,31,46,48]. The electromagnetic field is generated by a transmitter coil, which is typically integrated into the road, and a coupled receiver is installed on the vehicle, followed by a rectifier [5]. Moreover, inductive power transfer can also be designed for contactless or wireless power transfer, although very few authors consider wireless solutions [56,58–61].

The authors of [56] consider both conductive and inductive charging methods, where inductive charging is considered as a potential to provide power to vehicles on the move from the road surface, without the drawbacks of integrating sliding contacts into the ground. As a result, a broad range of concepts and design solutions for dynamic inductive power transfer are currently under development in [56–61], with the aim of being able to provide power to vehicles while the vehicle is in motion. The cost-optimized solution uses only conductive charging stations given the higher initial cost of inductive charging [5]. Nicolaides et al. [61] focus on defining the power requirements of a national electricity infrastructure suitable for the implementation of charge-on-the-move technology in Great Britain. In order to achieve this, the researchers are proposing a simulation tool to investigate the effects of system design variables and the dynamic charging process. The proposed infrastructure consists of 30 kW chargers, each with a length of 1.5 m, mounted every 2.1 m and every 4.3 m on highways and rural roads, respectively. The study's conclusion is that the implementation of this nationwide charging infrastructure could be economically feasible. Meanwhile, Guidi et al. [60] investigated the load balancing requirements of a new transformer-less grid interface configuration for large-scale EV charging infrastructures with a proposed configuration that employs a Modular Multilevel Converter (MMC) to power wireless EV chargers from each module.

A Battery Swapping Station (BSS) provides the end-user with a charged battery by physically exchanging the vehicle's battery. There are several challenges, including the current lack of a battery interface standard among EV manufacturers and user acceptance, to implementing battery swapping at scale [5]. In the work of Haugen et al. [62], given the increase in EVs and the demand for reduced charging time at fast charging stations (FCSs), which contributes to power peaks in distribution networks, battery storage is considered as an alternative to grid reinforcement. Therefore, a novel optimization model is developed with a stochastic generated load for FCSs as input, combining BSS operation and degradation, which minimizes operating costs for an actual FCS in Norway with a battery system.

In addition, the multiple and incompatible ISO/IEC/Society of Automotive Engineers (SAE) standards present a constraint to facilitate the implementation of EV technology: transcontinental or cross-border travel is not feasible at present, and the integration of EV charging technologies to provide ancillary services to the grid is compromised by different communication standards [5].

Since the barriers to entry are relatively low and bidding considerable, several companies are considering this field of operation, and competition is intense [47,50]. For example, more and more energy providers are offering these services. For a company, installation can provide reliable margins, although it is not particularly scalable as it is performed in the field and is highly dependent on labor [47,50]. The market is, therefore, mainly local and fragmented. The number of installers will increase over the next few years as demand starts to develop as the market matures, although revenues will have reached their maximum once the majority of charge points have been built [47,50].

3.2.2. Mobility Service Operator (MSO)

Most of the reviewed literature considered this service to be shared between the CPO and the DSO. This paper considers it an independent agent that interacts with these two operators by providing information about the energy management of the different charging stations, either given by the user when detecting an incident or by the service provider itself. For example, in [22,24,47,50–53,63], the authors analyze the influence that software regarding energy management could have on the power system and EV charging infrastructure. Therefore, MSO is responsible for offering the charging services, among other services and products related to end-users, prioritizing end-user comfort. Consequently, different studies have been carried out to analyze not only the benefits or its influence on the comfort-user side but also the influence that this software related to energy management could have on the electric system and the EV charging infrastructure.

Welsch et al. [52] develops an open-source energy model to evaluate the possible contribution from specific smart grid options, i.e., to investigate the impact of energy management on the power system. Thus, it is based on the Open Source Energy Modelling System (OSeMOSYS), which explains how "functionality blocks" can be introduced to reflect variability in electricity generation, preference of demand types, and changing demand and storage options. This paper demonstrates the flexibility and ease of using OSeMOSYS to modify code, which can serve as a useful tool for testing new functionality in widely used and more significant applications. Müller et al. [53], with the main purpose of increasing the quality, efficiency, and scope for policy makers and public actors involved in the European energy transition, reviews the several frameworks for introducing and categorizing models used in the analysis of energy systems. It emphasizes the tendency for a multi-purpose modeling representation, where the same data are accessible to all users. The paper suggests a tailored presentation according to the background and interests of different stakeholder groups (e.g., modelers, energy researchers, policy advisors, and policy makers). Moreover, in the work of Hilpert et al. [63] is established that, by providing an understanding of multiple development trajectories that require elaborate and flexible modeling tools, energy system models have become essential tools for planning future energy systems. Meanwhile, open science will play a growing role in energy system models, e.g., this paper provides a toolbox for building a comprehensive energy system model through collaborative development based on open processes, and introduces Open Energy Modelling Framework (oemof) as a novel approach to modeling, representing, and analyzing energy systems.

Furthermore, other studies focus on solving congestion at charging stations, i.e., reducing waiting time. Chowdhury et al. [22] introduces the challenges of modeling and sizing the capacity needed for EV charging infrastructure for systems with a slow dynamic component, including the potential for demand bursts during a peak hour interval. To address these concerns, a simulation tool focusing on a normal distribution representing events within a daily (24 h) or peak hour (rush hour) interval has been designed and integrated with a novel capacity planning methodology. Improving the level and quality of the EV charging service system is the main objective of the approach proposed in this study. Vandet and Rich [24] focuses on developing a space-time demand simulator for the movement of electric vehicles using travel records and incorporating models for optimal charging points, as well as incorporating the demand for charging into an information exchange system that provides predictions of the waiting time from the system to the users. The queueing theory is used to provide an approach for estimating waiting time as a function of generic station-specific inputs. The results show that "self-organization" in the system, where EV users are able to use range flexibility to advance or delay their charging decision to avoid congestion, significantly increases capacity utilization and reduces congestion in terms of waiting time.

Additional studies and research are accomplished in [51], which analyzes different approaches and also focuses on the necessary level of responsiveness that smart charging requires in terms of access to information from the battery management system. Thus, smart

charging should allow for rapid adjustments to address grid disturbances and emergencies. At this point, the MSO could act as a link between the CPO, the EV user, and the power system, as it is shown in Figures 2 and 3. Relevant and necessary data should be available to vehicle owners, users, and third parties acting on their account on the basis of a contractual agreement [47,51]. This emphasizes the need for cooperation regarding smart charging, which needs the different actors presented on the value chain of the EV charging ecosystem to work together (Figures 2 and 3), including Original Equipment Manufacturers (OEMs), to optimize the benefits while ensuring that EV batteries and the infrastructure of the system are preserved.

3.3. Power System Infrastructure

The power system infrastructure is composed of the distribution system and the transmission system. Distribution grids supply electricity to end-customers and are the connection points for industry and small and medium-scale distributed generation facilities, such as wind and solar farms. DSOs distribute electricity from the transmission grid to end-users, typically through MV networks (2 to 36 kV) and low-voltage (LV) (e.g., 50 Hz 230 V phase-to-ground in Europe or 60 Hz 110 V in the USA), [38].

The main concerns at the national or regional level are the efficient and secure operation of its power system. Calvillo and Turner [64] demonstrate the importance of the "smartness" and locating of EV charging for the cost of network reinforcement, which has an influence on the network investment and energy costs of different EV charging options. Several technical and economic factors must be considered to fully exploit the flexibility of electric vehicles [50]. In particular, a framework for purchasing flexibility by DSOs should be developed. Such a framework exists for the procurement of flexibility services through TSOs in the form of a balancing market [38,50]. Then, the TSOs present a plan of the balancing services (which includes the frequency regulation), the optimization of the network-wide costs of generation, and the support of the renewable energy sources [38]. The authors in [65,66] conducted an analysis to assess the benefits of cooperation within a European power grid with a significant share of renewable energy sources by considering two approaches to mitigate the variability in these sources, continental balancing through the transmission grid, and local balancing with the use of energy storage.

EV integration into distribution systems is demanding, by reason of the further restrictions that EV charging infrastructure can introduce, and rewarding, as smart charging or V2G can provide more flexibility for improving operations and planning [60]. Thus, EVs are able to support DSOs with a variety of services, including investment planning, congestion management, voltage regulation, and backup power supply in operational time frames. In addition, the economic value of the integration of electric vehicles into the electricity grid is studied in Wu and Lin [18], where a cost model of the electricity supply is established to investigate the cost reduction under three modes of charging operation, including random charging, controlled charging, and V2G charging.

Local peak demand should be considered when designing the ERS or static charging infrastructure connected to the local grid and can be used as a basis for selecting which roads to electrify initially [15]. Roads with high energy demand, including a high number of heavy-duty vehicles, should be preferred for an ERS since it can be assumed that a single electrified road system would be used primarily by trucks or buses that are being driven long distances on the same road [67].

3.3.1. Distribution System Operator (DSO)

Several studies analyzed the impact that electromobility, i.e., electric vehicles and EV charging infrastructure, could have on the distribution grid [9,10,13,38,41,43,60,68–77]. For example, in the work of Banol Arias et al. [75] is presented a review and classification of the services potentially available from EVs for distribution systems, referred to as EV distribution system services describing recent services and approaches.

The widespread deployment of EV charging infrastructure has the potential to have an impact on power systems, particularly distribution networks, due to the increase in EV penetration rates. These impacts can be categorized as load and voltage issues, which can result in active power losses, congestion of distribution system assets, degradation and failure of equipment, and affect the quality of the service provided to end-users [38]. However, positive effects such as mitigating the variability in renewable energy production and reducing the cost of renewable energy externalities can be achieved by integrating EVs into the power system. In addition, EVs can smooth the load curve of the power system and have an impact on the cost of power supply [18]. These effects depend on various factors such as EV penetration rates, user behavior, tariff systems, and network topology [38,48]. Maintaining the quality of service within reasonable limits is critical, and voltage problems may arise from EV charging, causing voltage drops and phase imbalances [38,48].

For simplification, we analyze the operation and planning of the distribution system from the point of view of the DSO. However, since several regulations may exist and require government involvement, more than one actor may be implied.

The DSO has to address various challenges regarding EVs and EV charging infrastructure integration in the distribution grid. In the work of Gonzalez Venegas et al. [38], it is established that V2G-able EVs faces considerable regulatory and technical challenges to provide flexibility and recommends simplifying and standardizing connection procedures and adapted metering options. EVs can support DSOs with various services, including investment planning, congestion management, voltage regulation, and backup power in operational time frames. It also describes the main barriers to the implementation of EVs flexibility services in distribution networks, which are both economic and institutional. In the work of ur Rehman [25] is analyzed the V2G system as an enabler for electricity supply companies to further improve power quality, with enhanced efficiency on both transmission and distribution sides, eliminating the chances of generator overloading.

Additionally, Banol Arias et al. [75] highlight various challenges and prospects for future research in the integration of EVs and renewable energy. The identified issues include market framework design, economic evaluation, battery degradation, and the impact of TSO service provision by EVs on distribution networks. The research suggests the need for further investigation into these factors to develop an effective strategy for integrating EVs and renewable energy into the power system. Alvarez Guerrero et al. [13] investigates the possible effects of integrating EVs and renewable energy into the power system during the annual summer peak and four weeks of high renewable energy and low loads. In both uncoordinated and coordinated EV charging scenarios, the results show overgeneration. A production cost model with 5 min time resolution and multiple planning horizons is used to assess the impact of variable generation and EV charging on the system. This study provides an overview of the effects of integrating EVs and renewables on system operating costs, EV charging costs, dispatch stacks, and backup reserves.

In Garau and Torsater [78], the potential of EVs for the improvement of the flexibility of power systems is under investigation. However, to describe the complex interactions between the different entities that comprise the distributed flexibility infrastructure, the modeling approaches used in this research area are insufficient. Examples include a monitoring system, realistic user behavior, and a driver influencing EV user behavior. The authors propose an agent-based modeling approach that analyzes the use of dynamic pricing strategies as a spatial flexibility tool to address this challenge. Given that the use of distributed flexibility is still emerging, the value that can be derived from providing flexibility is not yet fully understood.

3.3.2. Transmission System

System-wide services such as frequency control reserves and energy arbitrage for TSOs can be provided by the flexibility of the EV [38], where energy arbitrage consists of captur-

ing the value of price differences in the electricity market by adjusting the pricing process according to the strategies of TSOs in the electricity markets [5,38,50]. Moreover, Rauma et al. [79] studies EVs as a flexibility supplier with extensive commercial charging data, and introduces a method for identifying a load curtailment schedule with the least negative impact on charging service quality. It can serve the capacity market as a demand response [38]. Suggested methodologies may be beneficial to grid operations, reducing generation costs and facilitating renewable energy integration [38,80].

Possible process solutions based on cooperation between TSOs and DSOs are investigated in [38,81], as well as concepts for the provision of balancing power and congestion management, which may be applied in the future, when an increasing number of distributed units in the distribution network levels will provide it. Thus, Gonzalez Venegas et al. [38] demonstrate the need for increased DSO–TSO collaboration to facilitate flexibility emerging through all levels of the grid and to maintain the safe, secure, and reliable operation of the power system. In addition, Mowry and Mallapragada [82] considers that, to address concerns about range anxiety and thereby support economy-wide decarbonization goals, fast charging stations on highways for electric vehicles are necessary. As the EV charging infrastructure expands, the characteristics of these fast charging stations' electricity demand (e.g., high power requirements and spatial concentration) may adversely affect grid operations. In line with this, Strobel et al. [83] analyze the regional and national impacts of electric vehicles on the electricity system in Germany in 2030 at the regional level, as EVs consolidates their position as the leading decarbonization tool in the transportation sector. However, acting optimally to achieve one spatial objective often implies acting at another spatial level. This research quantifies the effect of optimized unidirectional electric vehicle charging at the national and regional levels in a case study of Germany 2030. Borozan et al. [23] also emphasize decarbonization efforts through the electrification of transport. However, there are several challenges, including excessive peak demand requiring significant infrastructure investment, to integrate EVs into the electricity system. In addition, the cost-effective system integration of electric vehicles is not possible unless intelligent charging concepts are implemented in combination with strategic grid expansion planning that considers the impact of uncertainties.

4. Analysis of Objectives for Agents and Operators in the Value Chain

Making the best or most effective use of a situation or resource is part of every optimization process. This is also true for part of the value chain, as different actors and agents will have particular objectives in their optimization process. The objective functions to be achieved by these different actors involved in the EV charging infrastructure value chain vary according to the particular requirements in operation or planning. In this paper, the objectives are classified into three main blocks: electric vehicle, EV charging infrastructure and service, and finally, power system infrastructure. Figure 5 presents a scheme of the different operation objectives considering the actors described in the previous section.

Regarding the electric vehicle, the category of electric vehicle ecosystem has been divided between the objectives related to the vehicle itself, its components and specifications, and the customer. The targets considered for the EV user emphasize the main concerns that the final user could have, such as range anxiety and the waiting and charging time of the vehicle.
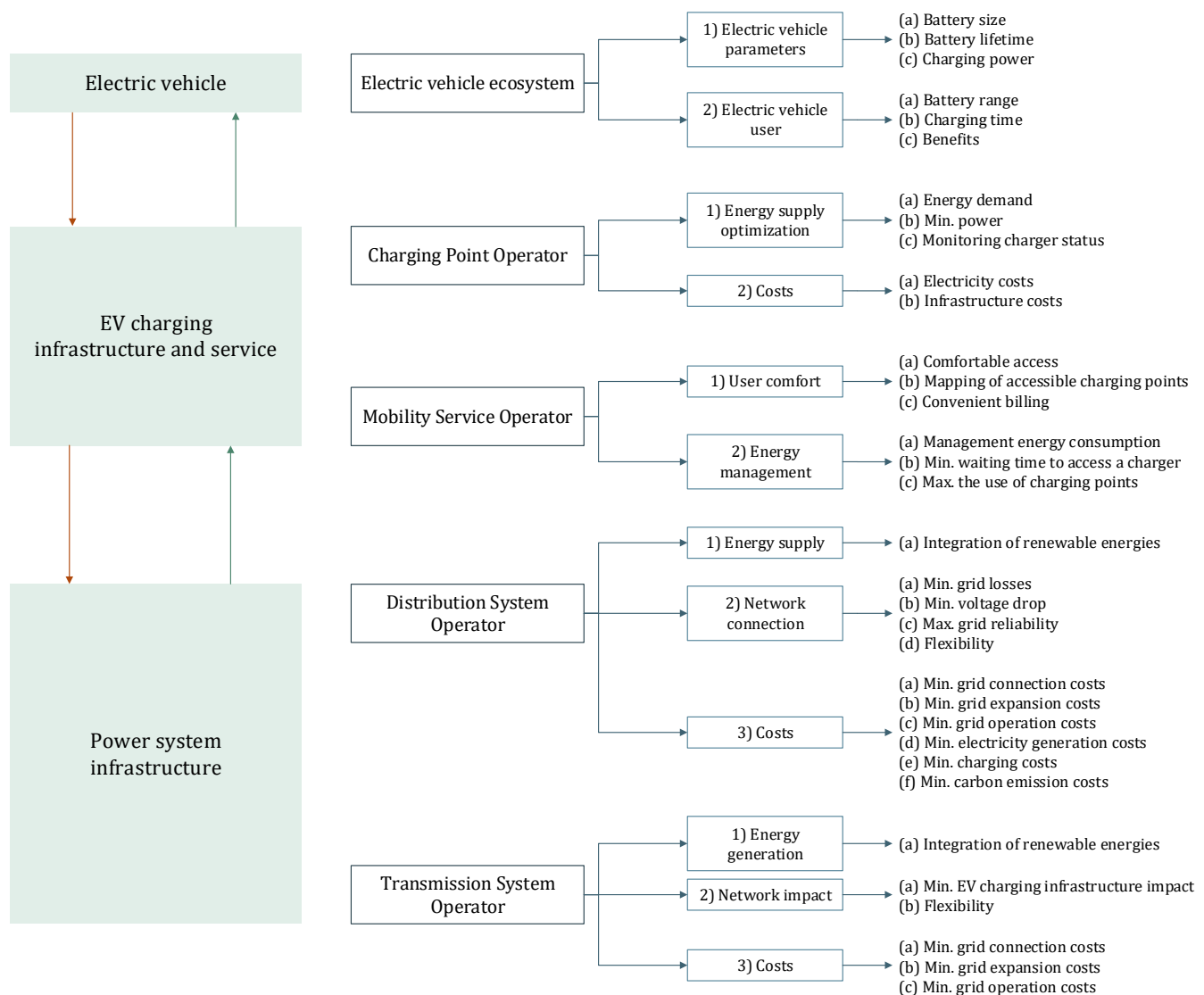
Figure 5. Value chain actors' main objectives.

Secondly, EV charging infrastructure and service have two subsections relating to infrastructure, the CPO and service and the MSO. Both are involved in managing EV charging points; however, they focus on different objectives. On the CPO side, the objectives analyzed may vary depending on the overall objective, which is optimizing energy supply or costs. Regarding the MSO, the objectives are related to the management of the information coming not only from the CPO or DSO to operate the recharging points but also from the end-user itself through some software, such as an app.

The third block, concerning the power system infrastructure, defines the objectives of the DSO and the TSO. Both operators have similar objectives since both operate the grid but on different scales.

Figure 6 illustrates the main papers analyzed, grouped in accordance with the classification described above (Figure 5). The chart shows that the majority of the papers focus on the second block, EV charging infrastructure and service. Meanwhile, in the third block, it is seen that there are fewer studies where the main objectives are related to the TSO.
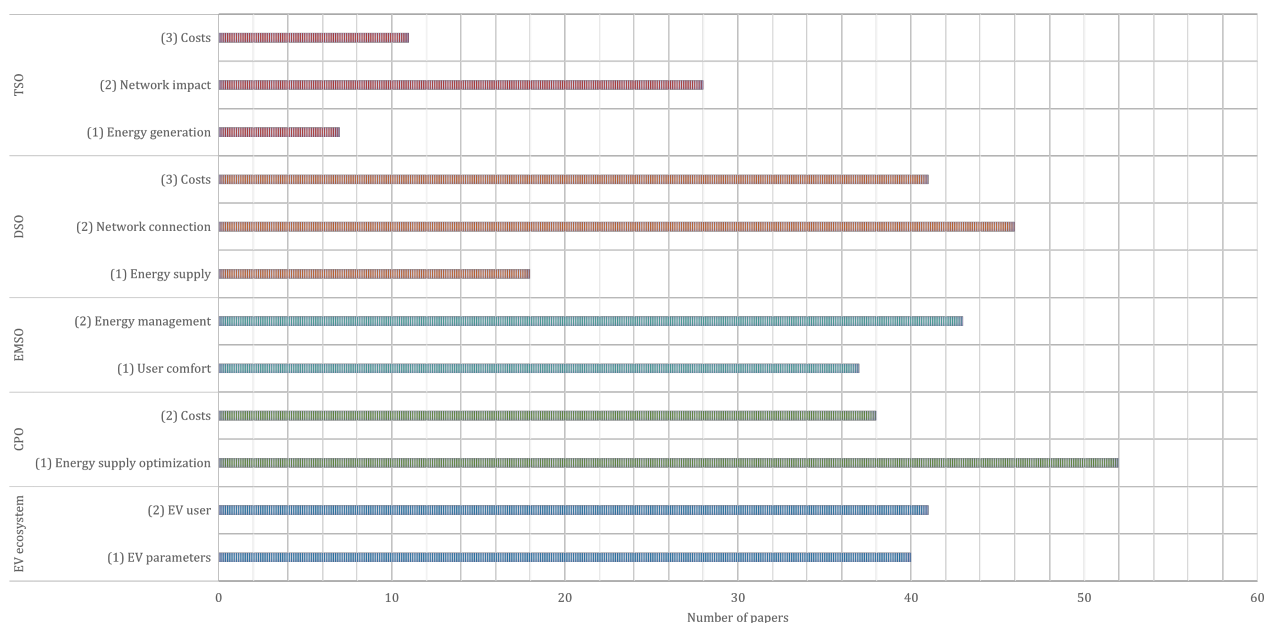
Figure 6. Classification of the main papers analyzed considering the operating objectives of the value chain.

Regarding the EV ecosystem, it is noted that more information can be found on the characteristics of the vehicle itself, mainly the battery size and charging power, such as is shown in [20,21,39,84], than on the EV user. However, there are several studies that analyze the relationship between the EV user behavior and another actor in the value chain, e.g., CPO or TSO. For example, [82] suggests that highway fast-charging stations are critical to address EV range anxiety. However, as the highway fast-charging infrastructure expands, its characteristics may negatively impact grid operations and increase the cost of system operation. These impacts can be effectively managed with mitigation strategies such as four-hour battery energy storage and transmission upgrades. Ref [85] focuses on workplace charging of EVs using local photovoltaic (PV) systems as offering economic and environmental benefits due to peak solar irradiation during working hours. However, the capacity of the grid connection can be strained by rudimentary charging management and high utilization. To address these issues, a nonlinear optimization model for coordinated charging within a local energy system is developed with the goal of minimizing the cost to the charging station operator and considering customer satisfaction. This optimized approach increases the use of locally generated solar power, reduces the cost of electricity, and allows for more vehicles to be charged simultaneously without increasing the grid connection capacity.

On the EV charging infrastructure block, it is noticed that the analyzed papers are mainly focused on the energy supply optimization, its costs as well as the energy management. For example, Refs. [24,29] emphasize the importance of cost considerations in planning EV charging infrastructure, notwithstanding the difference on the year of publications. Ghamami et al. [29] emphasizes the balance between charging delays, infrastructure costs, and battery costs, while Vandet and Rich [24] emphasizes the importance of considering social welfare and spatial variation in infrastructure costs. By integrating these perspectives, policymakers and planners can make informed decisions to create efficient and equitable EV charging infrastructure that meets the needs of users and benefits society as a whole.

However, there is also a trend to consider user comfort in studies such as [8,20,25,38,42, 84,86], using their travel routes or charging schemes. For example, in the work of Bagheri Tookanlou et al. [42], the focus is on developing an optimal scheduling scheme for grid-to-vehicle (G2V) andV2G operations at EV charging stations. The strategy aims to ensure that

all involved agents, including EV, EV charging stations, and electricity suppliers (ES), are rewarded. EVs independently plan their charging/discharging based on driving routes and cost–benefit considerations, while each EV charging station selects the best ES to purchase electricity from the wholesale market. Meanwhile, the work of Kavianipour et al. [8] focuses on alleviating EV range anxiety by proposing an integrated framework for urban fast charging infrastructure. The framework uses a simulation tool to generate driving paths and charging behavior based on driving attributes, which are used as input to a mixed-integer nonlinear program to determine the optimal charging station configuration. The approach outperforms alternative methods in terms of solution quality and computational efficiency, while minimizing system costs, including installation costs and charging delays. Infrastructure requirements for future market shares and technologies to support urban EV travel are also examined.

On the power system infrastructure side, the reviewed studies tend to emphasize the minimization of associated costs and optimization of the grid connection strategy. Many studies mention or rely on the use of smart charging and charging systems to ensure grid reliability and minimize the impact of the integration of charging stations and costs [18,23,25,26,28,38–40,86,87]. For example, Zhang and Yu [26] introduces a multistage system framework for the integrated design of an EV dynamic wireless charging system in a smart city. The framework includes an optimal placement strategy for power tracks based on city traffic information and EV energy demand, as well as a dynamic V2G scheduling scheme to coordinate EV schedules with V2G ancillary services. Simulation results demonstrate the effectiveness of the proposed model in improving placement strategy and V2G scheduling while achieving low economic system costs. In addition, [40] addresses the negative impact of EV charging stations on the operation of the distribution system and proposes a novel approach for their proper placement in a distribution network to maintain the performance of the system, by a test station in which V2G capability is designed. Thus, the effectiveness of the approach is validated and its ability to improve system performance without requiring physical network restructuring is demonstrated in a real-time distribution system.

An overview of the literature reviewed in this paper and the major operating objectives analyzed therein is presented in Table 2, sorted by year of publication, where the "x" symbol indicates items that take account of the objectives listed, while the "-" symbol indicates those that do not. In order to explain some of the interesting methodologies used to achieve these operational objectives, the following Sections 4.1–4.5 describe some of the papers listed in the classification tables.

Table 2. Overview of the objectives of existing literature works addressing the planning of electric vehicle charging infrastructure.

Year	Ref.	Electric Vehicle Ecosystem		Charging Station Operator		Mobility Service Operator		Distribution System Operator			Transmission System Operator		
		(1) EV Parameters	(2) EV User	(1) Energy Supply Optimization	(2) Costs	(1) User Comfort	(2) Energy Management	(1) Energy Supply	(2) Network Connection	(3) Costs	(1) Energy Generation	(2) Network Impact	(3) Costs
2014	[88]	-	x	x	x	x	-	-	-	-	-	-	-
2015	[34]	-	x	-	-	x	x	-	-	-	-	-	-
2016	[29]	x	x	x	x	x	-	-	-	-	-	-	-
2016	[89]	-	x	x	x	x	x	-	-	x	-	-	-
2017	[90]	-	-	-	-	-	-	x	x	x	-	-	-
2017	[81]	-	-	-	-	-	-	x	x	-	x	x	-
2017	[31]	x	x	x	x	-	-	-	-	x	-	-	-
2017	[30]	x	-	x	x	-	-	-	-	x	-	-	-
2017	[32]	x	-	x	-	-	x	-	x	-	-	x	-
2017	[91]	x	x	-	-	x	-	-	-	-	-	-	-
2018	[7]	x	x	x	x	x	x	-	x	x	-	-	-
2018	[14]	-	-	x	-	x	x	x	x	-	-	-	-
2018	[35]	-	x	x	x	x	x	-	x	x	-	x	-
2018	[92]	x	x	x	-	x	-	-	-	-	-	-	-
2018	[93]	x	x	x	x	x	x	-	x	x	-	x	x
2019	[61]	-	-	x	x	x	-	-	-	x	-	-	-
2019	[41]	x	x	x	x	x	x	x	x	x	-	-	-
2019	[43]	x	x	x	x	x	x	-	x	x	-	-	-
2019	[94]	x	x	x	x	-	-	x	x	x	x	x	-
2019	[11]	-	x	x	x	x	x	-	x	x	-	x	-
2019	[95]	x	x	x	x	-	x	x	x	x	-	x	x

Table 2. *Cont.*

Year	Ref.	Electric Vehicle Ecosystem		Charging Station Operator		Mobility Service Operator		Distribution System Operator			Transmission System Operator		
		(1) EV Parameters	(2) EV User	(1) Energy Supply Optimization	(2) Costs	(1) User Comfort	(2) Energy Management	(1) Energy Supply	(2) Network Connection	(3) Costs	(1) Energy Generation	(2) Network Impact	(3) Costs
2020	[96]	x	-	x	x	x	x	-	x	-	-	-	-
2020	[84]	x	x	x	-	x	x	-	x	x	-	-	-
2020	[42]	x	x	x	x	x	x	-	x	x	-	x	-
2020	[45]	x	x	x	x	-	x	-	-	x	-	-	-
2020	[4]	x	x	-	-	x	-	-	-	-	-	-	-
2020	[44]	x	x	x	-	-	x	x	x	x	-	-	-
2020	[15]	x	-	-	-	x	-	-	-	x	-	x	x
2020	[6]	-	-	x	-	-	x	-	x	-	-	x	-
2020	[36]	x	x	-	x	x	x	-	x	-	-	-	-
2021	[17]	x	-	-	-	-	-	-	-	x	-	-	-
2021	[40]	x	-	x	-	x	-	-	x	-	-	-	-
2021	[38]	x	x	-	-	x	x	x	x	x	x	x	x
2021	[97]	x	-	x	-	-	-	x	x	x	-	-	-
2021	[78]	-	-	x	-	-	-	-	x	x	-	-	-
2021	[55]	-	-	x	x	-	-	-	-	-	-	-	-
2021	[18]	x	-	-	x	-	-	-	x	x	-	x	x
2021	[49]	x	x	x	x	-	x	-	x	x	-	-	-
2021	[39]	x	x	x	x	x	x	-	x	x	-	x	-
2021	[8]	-	x	x	-	x	x	-	-	-	-	-	-
2021	[33]	x	x	-	-	x	x	x	x	x	x	x	x
2021	[48]	x	-	x	-	x	x	-	x	-	-	-	-
2021	[85]	-	x	x	x	x	x	x	x	x	-	-	-
2021	[82]	-	x	-	-	-	-	-	-	-	x	x	x
2021	[37]	x	x	-	x	-	-	-	x	-	-	-	-
2021	[47]	x	x	x	x	x	x	-	x	x	-	x	-
2022	[25]	-	x	x	x	x	x	-	x	x	-	x	-
2022	[86]	-	-	x	x	x	x	-	x	x	-	-	-
2022	[19]	-	x	x	-	x	x	-	-	x	-	x	x
2022	[20]	x	x	x	x	x	x	-	x	x	-	x	x
2022	[98]	x	x	x	-	-	x	x	x	x	-	-	-
2022	[21]	x	-	x	x	-	-	x	x	x	-	-	-
2022	[10]	-	-	x	-	-	x	x	x	x	x	x	-
2022	[26]	x	-	x	x	x	x	-	x	x	-	x	-
2022	[27]	x	x	x	-	-	-	-	x	-	-	x	-
2022	[28]	-	-	x	-	-	x	-	x	-	-	x	-
2022	[83]	-	-	x	-	-	x	x	x	-	-	x	-
2022	[87]	-	-	x	-	x	x	-	x	-	-	x	-
2022	[99]	-	-	x	x	x	x	-	x	x	-	x	x
2022	[22]	-	x	-	-	x	x	-	-	-	-	-	-
2022	[9]	x	-	x	x	-	x	x	x	x	-	-	-
2022	[5]	x	x	x	x	x	x	x	x	x	-	-	-
2022	[100]	x	x	x	x	-	-	x	x	x	x	x	-
2022	[23]	x	x	x	x	-	x	-	x	x	-	x	x
2022	[12]	-	x	x	x	x	x	-	-	-	-	-	-
2023	[24]	-	x	x	x	-	x	-	-	-	-	-	-

4.1. Operating Principle of Electric Vehicle Ecosystem

This section will analyze the objectives sought concerning the EV, for the two points of view described in Figure 5, the objectives related to the components or characteristics of the EV itself, and the benefits or user-related concerns for using an EV versus a conventional vehicle.

1. *EV parameters:* optimized the EV components and characteristics:
   (a) Battery size;
   (b) Battery lifetime;
   (c) Charging power.

2. *EV user:* focused on the EV user concerns and benefits:
   (a) Battery range;
   (b) Charging time;
   (c) Benefits.

Typically, EV targets result from compiling several primary indicators, including battery power, range, charging lead time, etc. In the following, the different subcategories are used to refer to the objectives or characteristics of each subcategory of objectives, as illustrated in Table 3.

4.1.1. EV Parameters

From the objectives described in Table 3 with respect to the EV, some of the papers analyzed for the different categories are described below.

a. *Battery size:* To focus on the issue of range anxiety, Ref. [8] investigates an integrated framework for urban fast charging infrastructure. Ref [17] notes that a wise choice of powertrain design is necessary to maximize the energetic performance achievable by a hybrid electric vehicle (HEV) as far as the on-road category is concerned. Thus, the model presented in that paper could be considered as an effective tool to support the HEV design optimization phases.

b. *Battery lifetime:* Ref. [38] indicates how battery degradation can represent a significant impediment to V2G-based services, having a major impact on the viability of business models for service flexibility. They propose algorithms and different practices to improve battery life with smart charging and V2G.

c. *Charging power:* Ref. [35] develops a travel pattern model based on the MCS, and then builds a bi-level charging station planning model with that EV traffic data. Also, the study conducted in [49] considers different conditions concerning EV charging infrastructure. First, it considers the capacity planning of public charging stations as an essential factor in facilitating the broad market penetration of EVs. Therefore, an optimization model for charging station capacity planning is presented to maximize the FQoS.

4.1.2. EV User

Based on the objectives described in Table 3 with respect to EV customers, some of the studies considered are analyzed for the different categories.

a. *Battery range:* Ref. [7] presents an overview of different studies examining infrastructure needs in relation to consumer preferences for this charging infrastructure, and the ways in which users interact with and exploit this infrastructure.

b. *Charging time:* Papers [7,29,88,101] analyze the problem of charging time that the EV user may have and how to address it. In [88], a mixed-integer programming model is developed to solve the problem of placing vehicle charging stations and maximizing the number of people who can accomplish round-trip itineraries. Ref. [7] reviews different types of methods and data sources used to analyze charging opportunities derived from the travel patterns of electric vehicle owners.

c. *Benefits:* In [33,38], from the end-user point of view, the benefits that can be obtained, such as bill optimization, self-consumption, and standby power, among others, are analyzed. The study also concludes that, while economic incentives can help increase user acceptance, other approaches, such as awareness raising, load data sharing, and even gamification, can increase end-user engagement.

4.1.3. Overview of EV Ecosystem Operating Principles and Opportunities for Improvements

Consumer preferences for charging locations, specifically convenient and cost-effective options like home and workplace charging, are important considerations in developing effective EV charging infrastructure [7,8,20,24,33,38]. Policy mechanisms such as cost reduction initiatives and consumer awareness campaigns have proven effective in promoting EV adoption [92]. Battery analysis plays a critical role in optimizing charging infrastructure and addressing challenges like congestion and charging delays [29,93]. Limited availability of charging infrastructure, particularly in certain regions or apartment complexes, can hinder the convenience and accessibility of EV charging [7]. Range anxiety, the fear of running out of battery power, is another concern that affects EV user confidence and their willingness to adopt electric vehicles. The fundamental questions of EV cost and range can only be answered with the support of a robust EV charging station infrastructure [9]. Thus, challenges remain, including limited charging infrastructure availability and range anxiety, impacting user convenience and confidence [7,9]. Despite these challenges, the EV industry offers significant benefits, such as reduced pollution, noise emissions, and oil dependence, contributing to transportation decarbonization [91,92]. Strategies have been

proposed to enable EVs to plan their charging/discharging based on driving routes and cost considerations, while EV charging stations select the optimal electricity supplier [42].

In summary, understanding consumer preferences for charging locations, implementing effective policies, and addressing challenges in battery technology and user concerns are crucial for the successful adoption of EVs and the development of sustainable charging infrastructure.

Table 3. Overview of the objectives of existing literature works addressing the electric vehicle ecosystem.

Ref.	(1) Electric Vehicle Parameters			(2) Electric Vehicle User		
	(a) Battery Size	(b) Battery Lifetime	(c) Charging Power	(a) Battery Range	(b) Charging Time	(c) Benefits
[88]	-	-	-	-	x	-
[34]	-	-	-	x	x	x
[29]	x	-	-	-	x	x
[89]	-	-	-	x	-	x
[31]	x	-	x	x	-	-
[30]	x	-	x	-	-	-
[32]	x	-	-	-	-	-
[91]	x	-	-	x	x	x
[7]	x	-	x	x	x	x
[35]	-	-	-	x	x	x
[92]	x	-	x	x	x	x
[93]	x	-	-	x	x	x
[41]	x	x	-	x	-	x
[43]	-	x	-	-	-	x
[94]	x	x	x	x	x	x
[11]	-	-	-	-	x	x
[95]	-	x	-	x	-	x
[96]	-	-	x	-	-	-
[84]	x	-	x	-	-	x
[42]	x	-	-	-	-	x
[45]	x	-	x	-	-	x
[4]	x	-	-	x	x	x
[44]	x	-	-	-	-	x
[15]	x	-	-	-	-	-
[36]	-	-	x	-	-	x
[17]	x	-	x	-	-	-
[40]	x	-	x	-	-	-
[38]	-	x	-	-	x	x
[97]	x	-	x	-	-	-
[18]	-	x	-	-	-	-
[49]	x	-	-	-	x	x
[39]	x	x	x	x	x	-
[8]	-	-	-	x	x	x
[33]	-	x	-	-	x	x
[48]	x	-	x	-	-	-
[85]	-	-	-	-	-	x
[82]	-	-	-	x	-	-
[37]	-	-	x	-	-	x
[47]	-	-	x	x	x	x
[25]	-	-	-	-	x	x
[19]	-	-	-	x	-	x
[20]	x	-	-	x	x	-
[98]	x	x	x	x	x	-
[21]	x	x	x	-	-	-
[26]	x	-	x	-	-	-
[27]	x	-	x	x	x	x
[22]	-	-	-	x	x	-
[9]	x	x	x	-	-	-
[5]	x	-	x	-	x	x
[100]	x	-	x	-	x	x
[23]	x	-	x	-	x	-
[12]	-	-	-	x	-	x
[24]	-	-	-	-	x	x

4.2. Operating Principle of Charging Station Operator (CPO)

In this part, the objectives pursued concerning the CPO are analyzed, so the main objectives functions for the hardware part of the EV charging infrastructure will be studied, as described in Figure 5.

1. *Energy supply optimization:* optimizing the EV charging demand:
    (a) Energy demand;
    (b) Min. power;
    (c) Monitoring charger status.

2. *Costs:* focused on the costs associated with the implementation or operation of the charging points:
    (a) Electricity costs;
    (b) Infrastructure costs.

Ideally, an optimal EV charging infrastructure results from a combination of factors, including the energy required to meet the demand, monitoring charger status to optimize their use, the associated costs, etc. The different sub-categories of objectives are discussed in more detail below. In the following, each sub-category's objectives are illustrated in Table 4.

4.2.1. Energy Supply Optimization

Based on the objectives described in Table 4 with respect to energy supply from the CPO perspective, some of the papers considered are analyzed for the different categories as examples.

a. *Energy demand:* Ref. [61] proposes to set out the requirements for the performance of a national electricity infrastructure suitable for the implementation of charging on the move. A simulation tool is presented that investigates the implementation of dynamic charging and the impact of system design variables from the estimation of the energy requirements of EVs also considering road traffic data for the predicted energy demand of Great Britain.

b. *Minimum power*: Ref. [96] presents a technique for modeling the electrical load of an electric road equipped with a dynamic wireless power transfer (DWPT) system and of the households in the nearby area. This paper presents a study of a stretch of Norwegian motorway where household and power load peaks occur at different times of day and seasons. Thus, it describes the dynamic charging of EVs and examines the resulting electricity load requirements, including the potential impact on the electricity distribution system.

c. *Monitoring charger status*: Ref. [42] designs a scheduling scheme that centered mainly on guaranteeing the rewards of all agents (e.g., EVs, charging stations, and ESs) participating in V2G and G2V operation. Thus, EVs individually plan their charging/discharging based on the shortest driving route and cost/benefit offered by charging stations. Moreover, with this approach, each charging station could find the optimal electricity supply to purchase electricity from the wholesale market.

4.2.2. Costs

From the objectives described in Table 4 with respect to the costs that the CPO may consider, some of the papers analyzed for the different categories are described as examples.

a. *Electricity costs:* A scheduling algorithm for the charging and discharging of EVs in public parking lots is proposed in [86]. The approach includes a demand response-based method to sell or purchase energy from electric vehicles during high and low price periods, respectively, based on maximizing the benefits of parking. The optimization procedure aims to maximize parking, vehicle, and distribution network benefits to reduce distribution network costs and increase financial benefits. In this mechanism, the strategy of load scheduling plays an important role.

b.　*Infrastructure costs*: Ref. [29] proposes an optimal configuration for PEV charging infrastructure along a corridor, aiming to minimize the overall cost of the system. The study emphasizes the importance of considering the balance between the cost of charging delays, infrastructure expenses, and battery costs. It highlights that, while charging delays and infrastructure costs are comparable, the cost of batteries is significantly higher, underscoring the need for cost-effective decision-making in planning EV charging infrastructure. Meanwhile, in the work of [24] it is suggested that optimal infrastructure could be designed from a social welfare perspective. To do so, infrastructure costs and their spatial variation with distance from the network must be better represented.

4.2.3. Overview of CPO Operating Principles and Opportunities for Improvements

CPOs face several challenges for EV adoption. Researchers have developed optimization models and heuristic approaches to maximize the number of users served and determine suitable locations for charging stations, taking into account budget constraints and round-trip itineraries. These approaches address the challenges of underdeveloped charging infrastructure and the planning of charging stations to support large-scale EV deployment [11,88,93].

One major challenge is the selection of optimal charging station locations, considering budget constraints and the impact on the number of potential EV users served [88,93]. Limited existing infrastructure poses limitations in realizing the optimal placement of charging stations, as the road and grid infrastructure were not developed with EVs in mind [93]. Therefore, the development of a well-established charging infrastructure is crucial to address concerns such as underdeveloped charging infrastructure and charge scheduling in charging stations, which requires exploring different approaches, objective functions, and optimization algorithms [9,93]

Thus, while the number of EVs continues to rise, the planning of the charging infrastructure must consider the power demand and load patterns. DWPT systems, such as charge-on-the-move technology, offer a solution for EV charging. Modelling the load from electric roads equipped with DWPT systems and existing household load patterns is crucial for long-term grid planning. Understanding the peak loads from different sources and their temporal variations enables efficient grid operation and planning [96].

To overcome these shortcomings, researchers have proposed optimization models and simulation tools to address the challenges of charging infrastructure planning and optimal placement of charging stations [24,41,96]. The integration of information-sharing systems to provide waiting time predictions to users has also been identified as a way to enhance the performance and utilization of charging systems [24].

In conclusion, from the perspective of CPOs, the shortcomings in the implementation of EVs revolve around the selection of optimal charging station locations, underdeveloped infrastructure, charge scheduling, integration with the power grid, and the need for information sharing. Addressing these challenges through optimization models, smart charging concepts, and information-sharing systems will be crucial in building a robust charging infrastructure to support the widespread adoption of EVs.

Table 4. Overview of the objectives of existing literature works addressing the charging point operator.

Ref.	(1) Energy Supply Optimization			(2) Costs	
	(a) Energy Demand	(b) Min. Power	(c) Monitoring Charger Status	(a) Electricity Costs	(b) Infrastructure Costs
[88]	x	x	x	-	x
[29]	-	-	x	-	x
[89]	-	x	-	-	x
[31]	x	x	-	x	x
[30]	x	x	-	x	x
[32]	x	x	-	-	-
[7]	x	x	x	x	-

Table 4. *Cont.*

Ref.	(1) Energy Supply Optimization			(2) Costs	
	(a) Energy Demand	(b) Min. Power	(c) Monitoring Charger Status	(a) Electricity Costs	(b) Infrastructure Costs
[14]	x	-	-	-	-
[35]	x	-	-	-	x
[92]	x	-	-	-	-
[93]	x	x	x	x	x
[61]	x	x	x	-	x
[41]	x	-	x	-	x
[43]	x	-	-	-	x
[94]	x	-	-	x	x
[11]	x	x	-	x	x
[95]	x	-	-	-	x
[96]	x	x	x	-	x
[84]	x	-	-	-	-
[42]	x	-	x	x	-
[45]	x	-	-	x	-
[44]	-	x	-	-	-
[15]	-	-	-	-	x
[6]	x	x	x	-	-
[36]	-	-	-	-	x
[40]	x	x	x	-	-
[97]	-	x	-	-	-
[78]	-	-	x	-	-
[55]	x	x	-	x	-
[18]	-	-	-	x	x
[49]	x	-	-	-	x
[39]	x	x	-	x	-
[8]	x	x	x	-	-
[48]	x	-	-	-	-
[85]	-	-	x	x	-
[37]	-	-	-	-	x
[47]	x	x	x	-	x
[25]	-	-	x	x	-
[86]	x	x	x	x	-
[19]	x	-	-	-	-
[20]	x	x	-	x	x
[98]	x	x	-	-	-
[21]	x	x	-	x	-
[10]	x	x	-	-	-
[26]	x	x	-	-	x
[27]	x	-	-	-	-
[28]	x	-	x	-	-
[83]	x	-	-	-	-
[87]	x	-	-	-	-
[99]	x	-	-	x	-
[9]	x	x	x	-	x
[5]	-	x	-	-	x
[100]	x	-	-	x	x
[23]	x	x	x	-	x
[12]	x	x	-	-	x
[24]	x	x	x	-	x

4.3. Operating Principle of Mobility Service Operator (MSO)

This part analyzes the objectives pursued concerning the MSO, so the main objectives of the software part of the EV charging infrastructure, as described in Figure 5, will be studied in contrast to the objectives of the CPO seen in Table 4. Thus, this operator usually manages the information provided not only by the CPO or DSO to manage the energy required but also by the end-user to meet their needs or concerns.

1. *User comfort:* centered on addressing the needs or concerns that the EV end-user may have.

    (a) Comfortable access;

    (b) Mapping of accessible charging points;

    (c)   Convenient billing.

2.   *Energy management:* focused on the optimization of energy from the CPO or DSO information on the supplied energy needed to cover the demand of electric vehicle charging points.

    (a)   Management energy consumption;
    (b)   Minimum waiting time to access the charger;
    (c)   Maximize the use of charging points.

An optimal EV charging infrastructure is the result of considering various pivotal factors, as mentioned in the previous sections; thus, different points of view should be considered, from hardware to software targets. In this case, the analysis is based on the software operator's point of view, which could be divided between end-user comfort and energy management. These objectives could include comfortable access and location of the recharging points, the comfort of billing, management of the energy consumption of these recharging points, etc. The different subcategories of objectives are discussed in more detail below. The objectives for each objective subcategory are illustrated in Table 5.

4.3.1. User Comfort

From the objectives described in Table 5 with respect to the user needs from the MSO perspective, some of the papers analyzed for the different categories are described as examples.

a.   *Comfortable access:* In [14] using a system dynamics model, two cause–effect pathways have been identified in the driving mechanism, which is mostly controlled by the key parameters of "Distribution of charging station" and "Planning of energy storage system". It is determined that, in constructing the hybrid model, the load satisfaction level and the integration of distributed renewable energy were mainly considered to make the distribution plan of charging stations more optimal.

b.   *Mapping of accessible charging points:* Ref. [61] describes the demands on the performance of a national electricity infrastructure for the implementation of on-road charging. Thus, a potential charging scheme is presented that includes infrastructure such as 30 kW chargers, each 1.5 m long, installed every 2.1 and 4.3 m on highways and rural roads, respectively.

c.   *Convenient billing:* In [5], a decision support tool is proposed for the planning of high-power charging infrastructure for EVs, considering the interests of all stakeholders, including DSOs, end-users, and service providers. The authors present guidelines and recommendations for a cost-effective and comprehensive charging infrastructure planning process by reviewing different methodological approaches proposed in recent research. The paper introduces the concept of "user cost", which includes the cost of purchasing electricity with a time-of-use component, the additional cost of traveling to get to the charging station, and the cost of parking.

4.3.2. Energy Management

Based on the objectives described in Table 5 with respect to energy management, as examples, some of the studies considered are analyzed for the different categories.

a.   *Management energy consumption:* Refs. [47,50–53,63] analyze the influence that software regarding energy management could have on the power system and EV charging infrastructure. Ref. [63] introduces an oemof as a novel method for modeling, representing, and analyzing energy systems, offering a collection of tools for creating detailed energy system models through collaborative development using open processes.

b.   *Minimum waiting time to access charger:* Ref. [25] suggests an optimal method for integrating electric vehicles into the smart grid using V2G technology and a network of charging stations, involving an hierarchical bi-directional aggregation algorithm. Ref. [24] focuses on using travel patterns to design a demand simulator for EV movements and incorporating models for optimal charging points, incorporating charging

demand into an information-sharing system that provides predictions of the waiting time from the system to the users.

c. *Maximize the use of charging points:* Ref. [86] addresses the problem of charging and discharging electric vehicles in public parking lots with the goal of maximizing the benefits for the parking lot. The proposed solution is a scheduling algorithm that uses an optimization process to coordinate the charging and discharging of vehicles to take advantage of high and low energy prices. The algorithm's main objective is to create a system that benefits the parking lot, vehicles, and distribution network as much as possible.

4.3.3. Overview of MSO Operating Principles and Opportunities for Improvements

From an MSO perspective, the widespread adoption of EVs is hindered by the limited travel range and inadequate charging infrastructure [35]. Zang et al. [35] propose a bi-level planning model for charging stations that maximizes the travel success ratio and considers the placement of charging stations on users' travel routes utilizing a queuing theory and a greedy algorithm to determine station capacity. Thus, comfortable access and sizing of charging stations, taking into account factors such as underdeveloped infrastructure, are key considerations for the large-scale deployment of EVs [93].

Comprehensive evaluation models and methods have been proposed to assess the network planning of charging stations, considering various factors such as spatial and temporal characteristics, user feedback, and operational impacts [20].

In addition, comfortable access and convenient billing are crucial perspectives in charging infrastructure [8,11,20,25,35,41,47,86,93]. Users require easy access to charging points, and efficient billing systems contribute to user satisfaction. Zang et al. [35] address this challenge, where the placement of charging stations on travel routes maximizes the travel success ratio, ensuring convenient access for users.

Energy consumption management and minimizing waiting time are important aspects of charging infrastructure [86]. Moreover, maximizing the use of charging points is crucial to ensure the efficient utilization of the infrastructure [35].

To summarize, even though there has been significant progress in the EV charging infrastructure planning, the studies conducted in this area still have addressed crucial aspects such as the placement, sizing, and joint deployment of charging stations. The consideration of factors such as user travel patterns, queuing theory, and distributed generation resources have been critical in this regard. However, certain limitations remain in terms of outdated infrastructure and a lack of focus on managing energy consumption, minimizing waiting time, and maximizing charging station utilization. It is recommended that future research should aim to overcome these limitations and provide comprehensive solutions for establishing an efficient and user-friendly EV charging infrastructure.

Table 5. Overview of the objectives of existing literature works addressing the mobility service operator.

Ref.	(1) User Comfort			(2) Energy Management		
	(a) Comfortable Access	(b) Mapping of Accessible Charging Points	(c) Convenient Billing	(a) Management Energy Consumption	(b) Min. Waiting Time to Access a Charger	(c) Max. the Use of Charging Points
[88]	x	x	-	-	-	-
[34]	x	x	-	-	x	-
[29]	x	x	-	-	-	-
[89]	x	x	-	-	-	x
[32]	-	-	-	x	-	-
[91]	x	-	-	-	-	-
[7]	x	x	x	x	-	-
[14]	x	x	-	x	-	-
[35]	x	-	-	x	x	x

Table 5. *Cont.*

Ref.	(1) User Comfort			(2) Energy Management		
	(a) Comfortable Access	(b) Mapping of Accessible Charging Points	(c) Convenient Billing	(a) Management Energy Consumption	(b) Min. Waiting Time to Access a Charger	(c) Max. the Use of Charging Points
[92]	x	-	-	-	-	-
[93]	x	x	x	x	-	x
[61]	x	-	-	-	-	-
[41]	x	-	-	x	-	x
[43]	-	-	x	x	-	-
[11]	x	x	-	x	x	x
[95]	-	-	-	-	-	x
[96]	x	-	x	x	-	-
[84]	-	-	x	x	-	-
[42]	-	x	-	x	-	x
[45]	-	-	-	x	-	-
[4]	-	-	x	-	-	-
[44]	-	-	-	-	-	x
[6]	-	-	-	x	x	x
[36]	x	-	-	x	-	-
[40]	x	x	-	-	-	-
[38]	x	-	x	x	-	-
[49]	-	-	-	x	x	x
[39]	x	-	-	x	-	-
[8]	x	x	x	x	x	x
[33]	x	-	x	x	-	-
[48]	x	x	-	x	-	-
[85]	x	-	x	x	-	-
[47]	x	x	x	x	-	x
[25]	x	-	-	x	x	x
[86]	x	-	-	x	x	x
[19]	-	-	x	x	-	-
[20]	x	x	x	x	x	x
[98]	-	-	-	x	x	-
[10]	-	-	-	x	-	-
[26]	-	x	-	x	-	-
[28]	-	-	-	x	-	-
[83]	-	-	-	x	-	-
[87]	x	-	-	x	-	-
[99]	-	x	-	x	-	-
[22]	-	x	-	x	x	x
[9]	-	-	-	-	x	-
[5]	x	x	x	x	x	-
[23]	-	-	-	x	-	-
[12]	-	-	x	x	-	x
[24]	-	-	-	x	x	x

4.4. Operating Principle of Distribution System Operator (DSO)

In this part, the objectives sought concerning the DSO will be analyzed, so the main objectives of the impact that an EV charging infrastructure could have on the grid at a local or regional level will be studied, as described in Figure 5.

1. *Energy supply:* optimizing the energy required to supply the grid to cover the energy demand for charging electric vehicles at a local or regional level.

   (a) Integration of renewable energies.

2. *Network connection:* focused on the issues that could influence the network due to the implementation of an electric vehicle charging infrastructure at a local or regional level.

   (a) Minimize grid losses;
   (b) Minimize voltage drop;
   (c) Maximize grid reliability;
   (d) Flexibility.

3. *Costs:* focused on the costs associated with the operation of the charging points in the grid from the DSO point of view.

    (a) Minimize grid connection costs;
    (b) Minimize grid expansion costs;
    (c) Minimize grid operation costs;
    (d) Minimize electricity generation costs;
    (e) Minimize charging costs;
    (f) Minimize carbon emission costs.

To ensure that an EV charging infrastructure operates as optimally as possible, a series of indicators must ideally be considered, as has been seen in the sections analyzed above. Moreover, the indicators analyzed in this work should be contemplated, as well as the communication that may exist between the different system operators and agents. From the DSO's point of view, the main objectives will be related to the impact on the network, connection, expansion, and operation at the local or regional level, also considering the associated costs, etc. The different sub-categories of objectives are discussed in more detail below. In the following, each sub-category's objectives are illustrated in Table 6.

Based on the objectives described in Table 6 with respect to the DSO perspective, some of the studies considered are analyzed for the different categories in Sections 4.4.1–4.4.3 as examples.

4.4.1. Energy Supply

a. *Integration of renewable energies:* The work in [33,38] examines the integration of electric vehicles into distribution systems and identifies the various technical, economic, regulatory, and user-related challenges and constraints.

4.4.2. Network Connection

a. *Minimize grid losses:* Ref. [90] presents an automated network planning tool that finds the optimal expansion planning measures for future network states aiming to reach a valid state without overloaded electrical equipment and without voltage limit violations at minimum cost. Therefore, the investment has a greater effect on preserving the network structure, since the tool prioritizes replacing equipment with shorter lifetimes, which present a higher risk of failure, and considers the cost of investing in new equipment.

b. *Minimize voltage drop:* In [97] a new approach has been proposed for determining the suitability of a distribution grid for accommodating EVs, which is not dependent on specific charging patterns and can be applied at any time. This method utilizes an MCS to evaluate the grid's capacity for EV charging. The results of the study have revealed that the grid's ability to accommodate EV charging is influenced by factors such as the minimum background voltage, maximum power consumption, and potential planning risks. This was demonstrated through its application to two existing LV networks.

c. *Maximize grid reliability:* Ref. [39] presents a new approach for the combined use of V2H and V2B technology in various scenarios, such as when employees own EVs, when a company operates a shared fleet of EVs, or in a leasing setup, among others. This approach leverages the energy storage capabilities of EVs to introduce a significant amount of electrical storage into the grid system without the need for additional investments, thus offering greater flexibility and mobility. The proposed technology has the potential to reduce peak demand on the grid and increase the use of renewable energy sources. The results indicate that the methodology is viable and can be applied to other cases, significantly contributing to improved energy efficiency, reduced peak demand in buildings, and increased EV adoption in transportation to workplaces.

d. *Flexibility:* Refs. [33,38] highlights that EVs can help postpone or prevent the need for costly upgrades in uncertain situations, thus decreasing the risk of unproductive investments. Therefore, EVs can help optimize the use of existing infrastructure by pro-

viding peak shaving and voltage support services, and by providing fault restoration or isolation services to minimize non-served power. Furthermore, flexibility platforms have the potential to create new business models. Ref. [42] focuses the flexibility on the benefits that the different agents and operators can obtain. They designed a scheduling scheme that mostly focuses on guaranteeing the benefits of various agents (e.g., EVs, charging stations, and ES) involved in V2G and G2V operation. Depending on the shortest driving route and the cost/benefit offered by charging stations, EVs independently schedule their charging/discharging. In addition, each EV charging station determines the most suitable ES to purchase electricity from the wholesale market.

4.4.3. Costs

a. *Minimize grid connection costs:* Ref. [43] suggests a multi-year high penetration management (HPM) plan using Cost Benefit Analysis (CBA) to minimize the financial effects of using PEV charging strategies in a distribution system. The plan is based on the optimal allocation of two different smart charging strategies at different points in the distribution system over the planning period. To evaluate the financial impact, the study takes into account a cost called "Cost of infrastructure upgrade", which refers to the cost of upgrading distribution lines due to increased congestion caused by increasing non-PEV and PEV loads over the planning period.

b. *Minimize grid expansion costs:* Ref. [44] presents a plan for expanding a distribution network to include EV charging stations and solar panels, which utilizes V2G technology in the operation of the charging stations to minimize expansion costs through smart V2G operation, taking into account uncertainties in solar energy availability. The model is formulated as an optimization problem and aims to minimize expansion costs by optimizing EV operation patterns while satisfying all technical constraints. The results obtained from the model indicate that the V2G operation in the charging stations reduces expansion costs by 450%.

c. *Minimize grid operation costs:* Refs. [33,38] examines various network tariffs that are used to cover the costs of operating and planning distribution and transmission grids. It notes that tariffs can vary based on time and location, with different rates for different time periods such as peak and off-peak hours or for different regions of the grid. Ref. [84] investigates EV scheduling strategies using CBA to obtain an optimal scheduling scheme. Thus, in order to maximize the benefits of integrating EVs into the distribution system, by applying Active Power Dispatch (APD) and Reactive Power Dispatch (RPD) to minimize system losses using V2G, the charging of EVs must be coordinated with the available V2G technology.

d. *Minimize electricity generation costs:* The authors of [18] evaluate the economic benefits of incorporating EVs into the grid using an electricity cost model. They examine cost reduction under three different charging modes: random charging, controlled charging, and V2G charging. The results indicate that the adoption of EVs can significantly enhance the power grid's load factor and decrease the cost of power supply. Additionally, the study found that the impact of the different charging modes on the power grid varies.

e. *Minimize charging costs:* The authors of [78] develop a method for analyzing the infrastructure of EV FCSs using an agent-based modeling approach. The algorithm takes into account EV user behavior and the variable energy pricing of high-power charging at different FCSs to assess the advantages of a dynamic pricing strategy for utilizing EV charging as a means of spatial flexibility. The findings reveal that dynamic pricing can be an effective means of influencing EV charging behavior and enhancing the flexibility of the active management of distribution systems.

f. *Minimize carbon emission costs:* The authors of [17] introduce a novel method for forecasting carbon dioxide emissions from HEVs. The model, which is based on deep neural networks, uses a pipeline of neural networks and a Dynamic Programming (DP) algorithm to identify the relationship between the design features of the HEV and

the main outputs of the DP, including the powertrain feasibility and CO_2 emissions from the tailpipe.

4.4.4. Overview of DSO Operating Principles and Opportunities for Improvements

The integration of EVs into distribution systems presents challenges and opportunities for DSOs. Various studies have explored the state of the art and methodologies used in this domain. Some studies emphasize the importance of network expansion planning, considering scenarios of additional distributed generation installation and the provision of balancing power [81,90]. Others propose multi-objective functions for EV charging station allocation, optimization models that jointly deploy EV charging stations and distributed generation resources, or investigate the impact of integrating EVs and charging infrastructure on distribution networks [14,41]. There have also been discussions on the potential of EVs to offer flexibility services and optimal siting of EV charging infrastructure [33,38]. The authors of [44,94] investigate the impact of integrating EVs and charging infrastructure on distribution networks, addressing load flow patterns, grid operation, and network expansion cost reduction through V2G technology. Mulenga et al. [97] develop a stochastic approach to estimate EV charging hosting capacity in distribution networks, considering uncertainties and charging sizes. Non-linear optimization models for coordinated EV charging and optimization strategies for distributed generation and EV programs have been proposed as well [85]. Some studies analyze the impact of EV integration on power quality, grid stability, and the interaction between EVs and renewable energy sources [21,98]. Galadima et al. [95] discuss optimal siting of EV charging infrastructure, considering its impacts on the distribution network and the integration of renewable energy resources. Lastly, the literature on the optimal planning of charging stations emphasizes the need for coordinated planning between transportation and distribution networks [10].

Moreover, optimizing grid connectivity, expansion, operation, electricity generation, charging, and carbon emissions costs is crucial. Minimizing grid connection costs is essential to maintain affordable power quality, and automated network expansion planning tools aid in long-term planning [9,10,90,95]. Optimizing the allocation of charging stations and distributed generation resources, considering vehicle-to-grid capabilities, minimizes electricity generation costs [9,10,21,33,38,41]. Minimizing charging costs requires considering factors such as charging satisfaction and stable power system operation [9,10,14,94,95,98,100].

While significant progress has been made in understanding and addressing the challenges of integrating EVs into distribution systems, several shortcomings remain. One common limitation is the lack of widespread implementation of bidirectional chargers and communication protocols for V2G technology, as noted by [33,38]. This limits the potential for EVs to provide flexibility services to the electricity system. Additionally, economic and regulatory barriers, such as a lack of regulatory frameworks to value flexibility at the distribution level, create uncertainty regarding the value of flexibility services offered by EVs [5,9,33,38,42,100]. Furthermore, the optimal siting and sizing of EV charging infrastructure is a complex task that requires coordination between transportation and distribution networks, but the literature lacks a comprehensive and unified approach to address this challenge [10].

Table 6. Overview of the objectives of existing literature works addressing the distribution system operator.

Ref.	(1) Energy Supply (a) Integration of Renewable Energies	(2) Network Connection (a) Min. Grid Losses	(b) Min. Voltage Drop	(c) Max. Grid Reliability	(d) Flexibility	(3) Costs (a) Min. Grid Connection Costs	(b) Min. Grid Expansion Costs	(c) Min. Grid Operation Costs	(d) Min. Electricity Generation Costs	(e) Min. Charging Costs	(f) Min. Carbon Emission Costs
[89]	-	-	-	-	-	-	-	-	-	x	-
[90]	x	x	x	x	-	x	x	x	x	-	-
[81]	x	-	-	-	x	-	-	-	-	-	-
[31]	-	-	-	-	-	x	x	x	-	x	-
[30]	-	-	-	-	-	x	x	x	-	x	-
[32]	-	-	-	-	x	-	-	-	-	-	-
[7]	-	-	-	x	x	-	-	-	-	x	-
[14]	x	-	-	x	x	-	-	-	-	-	-
[35]	-	-	-	x	-	x	-	x	-	-	-
[93]	-	x	x	x	-	x	-	x	-	x	-
[61]	-	-	-	-	-	-	x	-	-	x	-
[41]	x	x	x	x	x	x	x	x	x	x	x
[43]	-	x	-	x	x	x	x	x	-	x	-
[94]	x	-	-	x	-	-	-	-	-	x	-
[11]	-	x	-	x	-	-	-	x	-	-	x
[95]	x	x	x	x	x	x	-	x	-	x	-
[96]	-	-	-	x	-	-	-	-	-	-	-
[84]	-	x	-	x	x	x	x	x	-	x	-
[42]	-	-	x	-	x	-	-	x	-	x	-
[45]	-	-	-	-	-	-	-	-	x	x	x
[44]	x	-	-	-	x	-	x	-	-	-	-
[15]	-	-	-	-	-	x	x	-	-	-	x
[6]	-	x	x	x	x	-	-	-	-	-	-
[36]	-	-	-	-	x	-	-	-	-	-	-
[17]	-	-	-	-	-	-	-	-	-	-	x
[40]	-	x	x	x	-	-	-	-	-	-	-
[38]	x	x	x	x	x	x	-	x	x	-	-
[97]	x	-	x	x	x	-	x	-	-	-	-
[78]	-	-	x	x	x	-	-	x	x	x	-
[18]	-	-	-	x	x	-	-	x	x	x	-
[49]	-	-	-	x	x	-	x	-	-	-	-
[39]	-	-	-	x	x	-	-	x	x	x	-
[33]	x	x	x	x	x	-	-	-	x	-	-
[48]	-	x	x	-	-	-	-	-	-	-	-
[85]	x	x	-	-	-	-	-	x	-	-	-
[37]	-	-	-	-	x	-	-	-	-	-	-
[47]	-	-	-	x	-	-	-	-	-	x	-
[25]	-	-	x	x	x	-	-	x	-	x	-
[86]	-	-	-	x	x	-	-	x	-	x	-
[19]	-	-	-	-	-	-	x	x	-	x	-
[20]	-	-	x	x	-	-	-	x	-	x	x
[98]	x	-	-	x	x	-	-	x	-	x	-
[21]	x	x	-	x	x	-	-	x	x	-	-
[10]	x	x	x	x	-	x	x	x	x	x	x
[26]	-	-	-	x	x	-	-	x	-	-	-
[27]	-	-	-	x	x	-	-	-	-	-	-
[28]	-	-	-	x	-	-	-	-	-	-	-
[83]	x	-	-	x	-	-	-	-	-	-	-
[87]	-	-	-	x	-	-	-	-	-	-	-
[99]	-	-	-	x	-	x	x	x	-	x	x
[9]	x	x	x	x	x	x	x	x	x	x	-
[5]	x	x	-	-	x	-	x	x	-	x	-
[100]	x	-	-	x	x	-	-	-	-	x	-
[23]	-	-	-	x	x	-	x	x	x	-	-

4.5. Operating Principle of Transmission System Operator (TSO)

The last category will analyze the objectives sought in relation to the TSO; thus, the main objectives of an EV charging infrastructure's impact on the grid at a national level will be studied, as described in Figure 5.

1. *Energy generation:* optimizing the energy required to supply the grid to cover the energy demand for charging electric vehicles at a national level.
   (a) Integration of renewable energies.

2. *Network impact:* focused on the impact that the implementation of electric vehicle charging infrastructure could have on the grid at a national level.
   (a) Minimize EV charging infrastructure impact;
   (b) Flexibility.

3. *Costs:* focused on the costs associated with the operation of the charging points in the grid from the TSO point of view.

(a)   Minimize grid connection costs;
(b)   Minimize grid expansion costs;
(c)   Minimize grid operation costs.

In this case, among the objectives related to the TSO can be found the integration of renewable energies to support the grid (at the national level), minimizing the impact that the charging infrastructure can have on the grid, how flexibility can affect the grid, as well as the costs associated to a connection, operation, expansion, etc. The different sub-categories of objectives are discussed in more detail below. In the following, each sub-category's objectives are illustrated in Table 7.

From the objectives described in Table 7 with respect to the TSO perspective, some of the papers considered are analyzed for the different categories in Sections 4.5.1–4.5.3 as examples.

4.5.1. Energy Generation

a.   *Integration of renewable energies:* Ref. [100] examines a way to efficiently select the most suitable distribution route for mobile power supply from various options, by maximizing customer demand and minimizing costs, in order to increase the usage of PV power. It incorporates an energy blockchain to enhance the security of electricity transactions and designs the supply chain for PV-energy storage–charging. Thus, the study verifies the effectiveness and applicability of the proposed method by conducting parameter variation of NSGA-II and comparing it with two other algorithms, namely Genetic Algorithm (GA) and Multi-Objective Particle Swarm Optimization (MOPSO).

4.5.2. Network Impact

a.   *Minimize EV charging infrastructure impact:* Ref. [32] studies how energy demand fluctuates over time and location on a specific road and evaluates the effect of an electrified road on the stationary electricity system, considering different options for electrification and drive trains. The modeling results show that if static or electric road systems were implemented, the peak power demand for the hour of the regional power system sizing could potentially increase by 1–2%, assuming full electrification of the current traffic flow, which is comparable to that of a large industry. In addition, Ref. [20] proposed a comprehensive system and evaluation method for EV charging networks under the coupling of the road network and electric power system, by developing an EV displacement model based on the displacement probability matrix to analyze the spatial and temporal characteristics of EVs analyzing the coupling relationship among users, charging network, road network, and electric power system.

b.   *Flexibility:* In [25], for the integration of EVs in the Smart Grid (SG) using V2G technology through a charging station network, an optimal hierarchical bidirectional aggregation algorithm is proposed. The developed model predicts the power demand and performs day-ahead (DA) load scheduling in the SG by optimizing the charging/discharging tasks of EVs as a voltage and frequency stabilization tool in the SG. Ref. [26] proposes a multi-stage system framework to account for an integrated EV dynamic wireless charging system in a smart city considering both optimal placement strategy for installing charging points in a city road network and dynamic V2G scheduling.

4.5.3. Costs

a.   *Minimize grid connection costs:* Ref. [23] presents a multi-stage probabilistic planning framework, which can determine optimal investment strategies to minimize expected system costs and reduce the risk of failed investments. It shows that G2V, V2G, and V2B are effective off-grid alternatives to conventional reinforcement, providing significant economic savings and hedging against uncertainty.

b. *Minimize grid expansion costs:* Ref. [15] is a study on the feasibility of an electric road system in Norway and Sweden. The analysis takes into account factors such as traffic volume, the potential for reducing CO_2 emissions, and infrastructure costs to identify the most beneficial roads and vehicle types for electrification. The results show that 70% of the traffic and 35% of the total vehicle kilometers could be electrified by electrifying 25% of the selected roads. However, the investment in the infrastructure would be substantial, with an estimated cost in the range from EUR 2700 to 7500 million, assuming an ERS investment cost of EUR 0.4 to 1.1 million per km.

c. *Minimize grid operation costs:* Ref. [23] suggests G2V, V2G, and V2B investment and operation schemes for the problem of planning large-scale, long-term network expansion under multi-dimensional uncertainties. Ref. [20] presents a multilevel stochastic planning framework that can determine an optimal investment strategy that minimizes expected system costs and reduces stranded investment costs.

4.5.4. Overview of TSO Operating Principles and Opportunities for Improvements

The integration of EVs into power distribution systems presents challenges for TSOs [94]. Existing research has focused on user equilibrium models to analyze the flow of vehicles and electricity in these systems, aiding in long-term planning and short-term operation [94]. The implementation of an ERS in Norway and Sweden has demonstrated potential CO_2 emissions mitigation through partial or complete electrification [15]. V2Xs strategies have been suggested to increase EV penetration, reduce peak demand, and enhance energy efficiency [39].

However, there are some shortcomings. Integrated modeling approaches considering both transportation and power distribution networks are lacking, limiting the understanding of their combined effects [10]. Deregulation of the electricity market and supportive government measures are needed for the active participation of EVs as a power source [18]. Consideration should be given to the increase in regional peak loads and the trade-off between national and county-level optimization [83]. Accurate representations of mobility and charging patterns specific to each country are crucial, along with mechanisms for smart V2G interactions [28].

While the studies provide valuable insights, further research is necessary to address the identified shortcomings and enhance the understanding of the interplay between transportation systems, power distribution systems, and EV integration [15,18,39,42,94]. Transmission system operators can benefit from a more comprehensive understanding and integrated modeling approaches to optimize power grid operation and planning in the context of increasing EV adoption.

Table 7. Overview of the objectives of existing literature works addressing the transmission system operator.

| Ref. | (1) Energy Generation | (2) Network Impact | | (3) Costs | | |
	(a) Integration of Renewable Energies	(a) Min. EV Charging Infrastructure Impact	(b) Flexibility	(a) Min. Grid Connection Costs	(b) Min. Grid Expansion Costs	(c) Min. Grid Operation Costs
[81]	x	-	x	-	-	-
[32]	-	x	x	-	-	-
[35]	-	x	-	-	-	-
[42]	-	x	x	-	-	-
[15]	-	x	-	-	x	-
[6]	-	x	x	-	-	-
[38]	x	x	x	x	-	x
[18]	-	x	x	-	-	x
[39]	-	x	x	-	-	-
[33]	x	x	x	x	-	-
[82]	x	x	-	-	-	x

Table 7. *Cont.*

Ref.	(1) Energy Generation	(2) Network Impact		(3) Costs		
	(a) Integration of Renewable Energies	(a) Min. EV Charging Infrastructure Impact	(b) Flexibility	(a) Min. Grid Connection Costs	(b) Min. Grid Expansion Costs	(c) Min. Grid Operation Costs
[47]	-	x	-	-	-	-
[25]	-	x	x	-	-	-
[19]	-	x	-	-	-	x
[20]	-	x	-	-	-	x
[10]	-	x	-	-	-	-
[26]	-	x	x	-	-	-
[27]	-	-	x	-	-	-
[28]	-	x	-	-	-	-
[83]	-	x	-	-	-	-
[87]	-	x	-	-	-	-
[99]	-	x	-	-	x	x
[100]	x	x	x	-	-	-
[23]	-	-	x	x	x	x

5. Conclusions

This paper analyzes the literature on the different agents and operators involved in the planning of public charging infrastructure for electric vehicles. Based on the value chain considered in this paper, the different objectives pursued by each operator have been analyzed and categorized to provide a comprehensive review of the literature. First, the value chain and its proposed division for electric vehicle public charging infrastructure are presented, providing an overview of the actors interacting in the charging infrastructure ecosystem. Then, the several implications or objectives of the different actors, described as agents or operators, are analyzed in the planning of public electric vehicle charging infrastructure. These defined roles in the charging infrastructure ecosystem follow defined categories ranging from the user (electric vehicle) to the charging point operator (CPO), and then to the mobility service operator (MSO), and finally to the local grid (LV and MV distribution networks), the distribution system operator (DSO), and to the regional or national level (transmission level, wholesale markets), the transmission system operator (TSO). Furthermore, a review of the different aspects involved in the different roles established is presented, starting with the electric vehicle itself and the end-user, passing through the CPO who is in charge of operating the charging stations, followed by the MSO, who provides information on the location of the charging stations, managing energy consumption and charging cost, etc., to increase the convenience of the EV agent user, and finally, the DSO and TSO manage the electricity supply from the grid to the charging point at the local and national level, respectively. Finally, based on the previous analysis and the literature review studied for this paper, a summary divided into different tables is provided, detailing information related to these studies categorized according to the characteristics mentioned for each actor of the value chain defined for this paper. It is concluded that research regarding optimal planning of public charging infrastructure considering several actors is currently at an early stage. A considerable part of the literature review analyzes the electric vehicle charging infrastructure from the point of view of a single actor, thus making the planning inefficient and potentially impacting other actors in the system negatively. More recent studies are beginning to study the impacts and benefits of cooperation and coordination between the different operators in order to make public planning as optimal as possible from a holistic point of view, but they are still not sufficient or do not consider all the agents that may interfere in the planning of the charging infrastructure. In addition, it has been observed that the higher the degree of cooperation and coordination, the more benefits the use of EVs could have for the grid in terms of flexibility, i.e., from V2G/V2B/V2H/V2X to using EVs as storage systems to support renewable energies in order to provide stability to the grid. Therefore, it is concluded that more cooperation and coordination between the

different actors presented in the value chain of this paper is needed (CPO-MSO-DSO-TSO), as well as taking into account the needs and behaviors of the end-user to see the benefits of using an EV instead of an ICEV.

Future research directions within the topic of public EV charging infrastructure will aim to attain multiple objectives that will significantly enhance the planning and operational procedures. Firstly, there arises a need for the development of advanced optimization models and algorithms that conscientiously account for diverse factors such as charging demand patterns, grid limitations, and expansion costs of the infrastructure. These models possess the capability to ensure prudent resource utilization and mitigate any adverse impacts on the electric grid by optimizing the optimal location and sizing of charging stations. Secondly, research can be targeted at formulating smart charging policies that take into account real-time data on energy costs, renewable energy availability, and the current state of the grid. These policies can include dynamic pricing schemes and load management techniques to optimize charging schedules and mitigate peak demand pressures. There is also growing interest in exploring the integration of energy storage systems into the charging infrastructure to enhance grid stability and enable bi-directional vehicle-to-grid interactions. Finally, the implementation of smart grid technologies and communication protocols can have significant importance in improving the monitoring and control of the charging infrastructure, facilitating efficient coordination and interoperability among distinct charging stations and energy management systems. Therefore, these potential future research directions hold great promise for developing a more efficient, reliable, and sustainable public charging infrastructure.

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Abbreviations

The following abbreviations are used in this manuscript:

AC	Alternating current 8, 11
AFID	Alternative Fuels Infrastructure Directive 1
APD	Active Power Dispatch 31
BEV	Battery Electric Vehicle 6, 7
BSS	Battery Swapping Station 11, 12
CBA	Cost Benefit Analysis 31
CPO	Charging Point Operator 2–4, 10, 11, 13, 14, 18, 24, 27, 35, 36
DA	Day-Ahead 35
DC	Direct Current 8, 11, 12
DP	Dynamic Programming 32

DSO	Distribution System Operator 3, 4, 13–16, 18, 27, 30, 35, 36
DWPT	Dynamic Wireless Power Transfer 24
ERS	Electric Road System 2, 9, 12, 14, 35
ES	Electricity Suppliers 19, 24, 31
EU	European Union 1, 2
EV	Electric Vehicle 1–19, 21, 22, 24, 25, 27, 28, 30–32, 34–36
EVSE	Electrical Vehicle Supply Equipment 1
FCEV	Fuel Cell Electric Vehicle 9
FCS	Fast Charging Station 12, 32
FCV2G	Fuel Cell Vehicle-To-Grid 9
FQoS	Fuzzy Quality of Service 10, 21
G2V	Grid-To-Vehicle 19, 24, 31, 35
GA	Genetic Algorithm 34
HDV	Heavy Duty Vehicle 6, 11
HEV	Hybrid Electric Vehicle 21, 32
HPM	High Penetration Management 31
ICEV	Internal Combustion Engine Vehicle 1, 36
IEC	International Electrotechnical Commission 11, 12
ISO	International Organization for Standardization 11, 12
km	Kilometer 11, 12, 35
kW	Kilowatt 8, 9, 11, 12, 27
LDV	Light Duty Vehicle 6
LV	Low-Voltage 14, 31, 35
m	Meter 9, 11, 12, 27
MCS	Monte Carlo Simulation 7, 21, 30
MMC	Modular Multilevel Converter 12
MOPSO	Multi-Objective Particle Swarm Optimization 34
MSO	Mobility Service Operator 2–4, 10, 13, 14, 18, 27, 35, 36
MV	Medium-Voltage 9, 14, 35
MW	Megawatts 8, 11
O&M	Operations and Maintenance 8
OEM	Original Equipment Manufacturer 14
oemof	Open Energy Modeling Framework 13, 28
OSeMOSYS	Open Source Energy Modeling System 13
PEV	Plug-In Electric Vehicles 7, 22, 25, 31
PHEV	Plug-in Hybrid Electric Vehicle 6, 7
PV	Photovoltaic 18, 34
RPD	Reactive Power Dispatch 31
SAE	Society of Automotive Engineers 12
SG	Smart Grid 34, 35
TSO	Transmission System Operator 3, 4, 14–16, 18, 34–36
V2B	Vehicle-To-Building 8, 31, 35, 36
V2G	Vehicle-To-Grid 5, 6, 8, 14, 15, 19, 21, 24, 28, 31, 32, 34–36
V2H	Vehicle-To-Home 8, 31, 36
V2X	Bidirectional Charging 8, 36
VMT	Vehicle-Miles-Traveled 7
VPP	Virtual Power Plant 8

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