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Electric Vehicles: A Comprehensive Review of Technologies, Integration, Adoption, and Optimization

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ABSTRACT The transport sector has experienced a boom in electric mobility over the past decade as it moves towards a more sustainable future associated with the Sustainable Development Goals (SDGs). This paper provides a comprehensive review of the existing literature on important aspects of electric vehicle development, including technical, social, and methodological viewpoints. This paper presents an overview of electric vehicle (EV) operations, including discussions on the technology, charging modes and standards, as well as charging coordination and control. The paper also examines the potential benefits and consequences of integrating EVs into power systems. The paper thereafter presents the reader with a concise overview of the key elements and obstacles that are acknowledged as crucial to the widespread adoption and market expansion of EVs globally. Ultimately, we examine many areas of focus for improving efficiency in the operations and planning of EV integration into power grids.

INDEX TERMS Plug-in electric vehicles (PEV), smart charging, vehicle to grid (V2G)

I. INTRODUCTION

The transport sector is increasingly solidifying its place as one of the most significant sectors in terms of energy use. Despite being influenced by multiple variables such as the COVID-19 pandemic and the energy crisis, its proportion of energy utilization reached 25% of the overall final consumption (TFC) in 2023, with fossil fuels serving as the primary energy source [1] .Transportation is responsible for 32% of direct CO_2 emissions from burning fuel. Specifically, road vehicles such as cars, buses, and two and three wheelers are accountable for nearly three quarters of these emissions [2]. Consequently, there has been a continuous and increasing endeavor worldwide to promote the advancement of electric transportation as a viable solution to reduce the

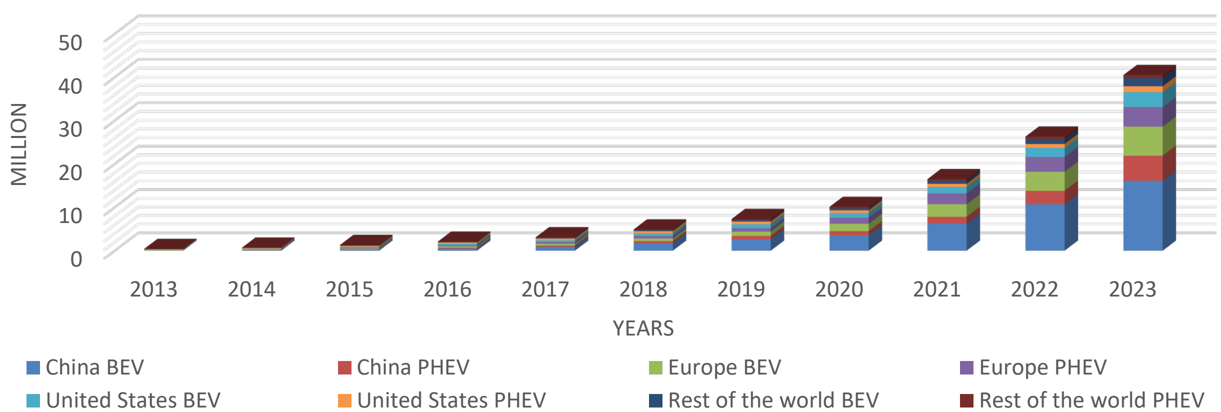

FIGURE 1. Worldwide inventory of EV, 2010-2023

rise in carbon emissions and greenhouse gases, while also decreasing reliance on fossil fuels.

The current prospects of the electric vehicle (EV) sector demonstrate a significant level of interest. The worldwide EV market has undergone significant expansion in recent years, as indicated by the data presented in Fig.1 [3]. In the chart, BEV refers to battery EVs while PHEV refers to plug-in hybrid vehicles. In 2023, the number of EVs in use surpassed 3.5 million, representing a growth of around 35% compared to the previous year. This increase can be attributed to the rising interest and investment from people and governments in EV technology and the necessary infrastructure to support it [3]. Figure 2 presents a comprehensive view of the EV market share distribution across various countries for the year 2023. This chart provides valuable insights into the differing levels of EV adoption worldwide and highlights the influence of national policies, infrastructure development, and consumer behavior on the penetration of EVs in the automotive market. Norway leads with over 90% of new automobile sales being electric, highlighting its robust adoption driven by significant governmental incentives and widespread charging infrastructure. China follows with approximately 40% market share, supported by its extensive investment in EV technology and infrastructure, including a vast network of public charging stations. The chart also compares the market share of other major regions, such as the European Union (EU), the United States (US), and emerging markets. The EU shows varied levels of EV market penetration across its member states. Countries like Germany and the Netherlands are leading the charge with significant market shares, while others are still in the early stages of adoption. This variation reflects differences in national policies, economic incentives, and infrastructure development within the EU. In the US, the EV market share stands at around 18%. While this represents significant growth from previous years, the adoption rate is slower compared to Norway and China. Factors contributing to this include varying state-level incentives, differing consumer preferences, and challenges in expanding charging infrastructure across the country. The chart also depicts market shares in emerging markets and other developed nations. These regions show lower penetration rates, indicating that EV adoption is still in its nascent stages. Factors such as economic conditions, lack of infrastructure, and limited government support play significant roles in these lower adoption rates [3], [4], [5], [6], [7].

This data in Figure 2 not only reflects a substantial increase in consumer adoption rates but also indicates broader changes in the automotive industry and governmental policies favoring eco-friendly alternatives. Some factors contributing to EV market growth can be summarized as follows:

Government Incentives and Regulations: Governments worldwide have introduced various incentives, such as tax rebates, grants, and subsidies, to make EVs more accessible and attractive to consumers. Additionally, stringent emissions regulations have pressured automakers to increase their offerings of low-emission vehicles. For instance, the implementation of the European Union's strict CO_2 emissions targets has propelled significant investments in EV technology by major automotive manufacturers, contributing directly to the surge in EV numbers.

Technological Advancements: Technological improvements in battery technology have played a crucial role in this growth. The development of lithium-ion batteries with higher energy densities and lower costs has extended the range of EVs while reducing their price, making them a viable option for a broader consumer base. For example, the average cost of lithium-ion batteries per kilowatt-hour has decreased significantly over the past decade, correlating with the increase in EV adoption.

Consumer Awareness and Preferences: There is a growing awareness and concern about environmental issues among consumers, which has led to increased demand for sustainable alternatives. The shift in consumer preferences is reflected in the rising sales of EVs, as individuals look to reduce their carbon footprint. Surveys indicate that consumers are increasingly considering EVs as their primary or secondary vehicles, driven by both environmental concerns and lower long-term ownership costs.

Expansion of Charging Infrastructure: The expansion of charging infrastructure has further supported the EV market growth. Public and private investments in charging stations have reduced range anxiety, making EVs a more practical choice for everyday use. The correlation between the availability of charging infrastructure and EV adoption rates is evident in urban areas, where increased charger density has accelerated the adoption of EVs.

This rapid growth in the EV market has profound implications for the automotive industry, energy markets, and global efforts to reduce greenhouse gas emissions. It suggests a pivotal shift towards an electrified future, promising reduced dependence on fossil fuels and lower emissions. However, it also poses challenges such as the need for increased electricity generation, potential strain on electrical grids, and the critical requirement for sustainable battery production and recycling processes.

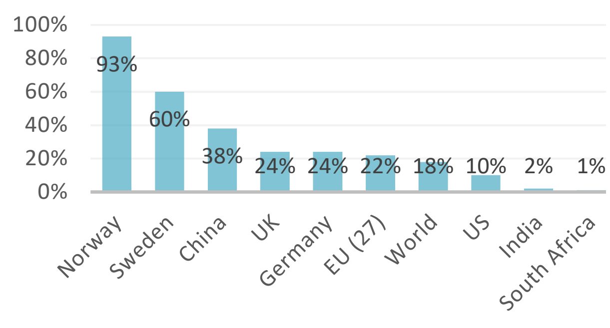

FIGURE 2. Global Electric Vehicle Market Share by Country in 2023

The ACEA, the European Automobile Manufacturers' Association, represents European car manufacturers. Electrically-chargeable vehicles, including battery electric and plug-in hybrids, make up 21.6% of new passenger cars in the EU. Hybrids, on the other hand, account for 22.6% of total car sales for the 2018-2022 timeframe [8]. China now dominates the global electric vehicle supply equipment (EVSE) market, boasting over 85% of the world's fast chargers and over 60% of slow chargers. China has already exceeded its goal for electric car sales, with a market share of over 35%, surpassing its objective for 2025. Now, China is shifting its attention to developing charging infrastructure. The aim is to have complete coverage of charging stations in cities and highways by 2030 and expand coverage in rural areas. As of 2023, an estimated 3.5 million charging stations have been installed globally. 2023, there was a 40% increase compared to the previous year. Out of the total number of charging stations, almost 1.84 million were categorized as slow charging stations, whereas 1.4 million were classified as fast charging stations [3].

Innovative EV business models with unique benefits have both encouraged the shift to electric mobility and painted a promising future for the industry. These innovative business models, such as car sharing, battery swapping, and leasing models, are not just trends, but potential game-changers in the EV industry. They are being scrutinized to comprehend their impact on EV adoption and the generation and capture of value [9]. Furthermore, the potential to create value for EV adopters through intelligent grid technology is a significant driver in the proliferation of EV technology and its allure to potential adopters. This will be elaborated upon in the next section.

A range of advanced technologies in the Vehicle-Grid Interface (VGI) has crucially promoted EVs as a viable option for sustainable energy transition. EVs not only function as a storage system capable of supplying electricity back to the grids through a demand response service, but also have the potential to offer auxiliary services to the grid. These technologies offer significant benefits for customers, utilities, governments, and society, leading to a brighter, more sustainable future [10]. However, if the integration of EVs into power grids is not effectively managed or controlled, it could lead to significant negative consequences [9]. Therefore, it is not just a matter of optimizing the benefits, but also of limiting and preventing the undesirable impacts. Due to the complex nature of integrating EVs into the power grid, which often requires making conflicting decisions, mathematical optimization methods are employed to determine the best decisions that achieve several objectives [11]. This underscores the critical importance of effective management in this context.

Various governments throughout the globe are implementing strategies and constructing infrastructure to facilitate the transition to EVs to meet their sustainability objectives at both national and global levels. However, not all countries have a clear roadmap for accomplishing these goals. In order to successfully integrate EVs into the mainstream, various factors need to be considered. These include antecedents, drivers, and mediating and moderating variables, which play a crucial role in determining the widespread adoption of EVs and their positive impact on the environment and economy [12].

In order to present a clear and structured overview of the various aspects covered in this study, a block diagram (Figure 3) is provided to summarize the key elements of EV integration and its impact on power systems. This diagram outlines the main sections of the paper, guiding readers through the progression from EV market growth to the technological, operational, and grid-related challenges, and finally to the optimization strategies and future trends in the EV domain.

- **EV Market Growth**: This block highlights the rapid expansion of the global EV market, driven by technological advancements and supportive government policies. EV market growth already is discussed in the Introduction Section. This growth serves as the foundation for the rest of the paper.
- **EV Technologies and Operations**: This section delves into the various types of EVs, the infrastructure required to support them, and the mechanisms by which EVs interact with the power grid. It covers essential aspects such as charging modes, standards, and smart charging strategies like V1G and V2G.
- **Impact on Power Grid**: As EV adoption increases, their integration into power systems presents challenges, including load profile alterations, power quality issues like harmonics and voltage imbalances, and stress on grid assets. These topics are discussed in detail, with a focus on how they affect grid stability and reliability.
- **Adoption of EV**: This section examines the factors that influence the widespread adoption of EVs, focusing on both the drivers and barriers that affect consumer decisions and market dynamics. It explores the role of governmental incentives, public awareness, infrastructure availability, and technological advancements in accelerating EV adoption.
- **Optimization and Future Trends**: The final section of the diagram addresses the strategies for optimizing EV integration, including load management and grid modernization efforts. It also explores future trends and innovations that could shape the future of EVs and their role in energy systems.
- **Key Insights and Challenges**: The conclusion summarizes the key insights gained from this comprehensive review and highlights the challenges that remain for the successful and widespread adoption of EVs.

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This diagram serves as a roadmap for the paper, making the structure and flow of the content more accessible and allowing readers to grasp the novelty and scope of the study at a glance.

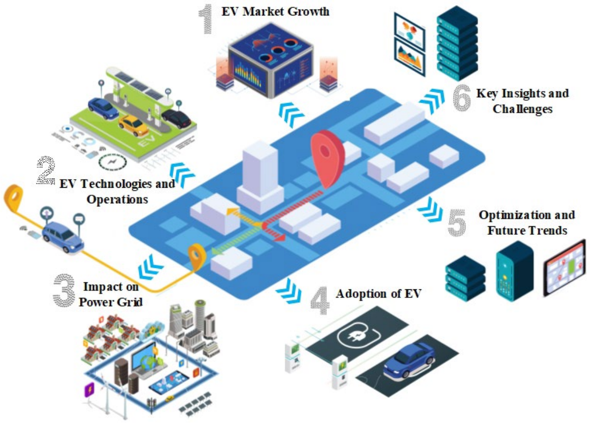

FIGURE 3. **Structural representation of the review paper**

II. EV TECHNOLOGIES and OPERATIONS

This section presents a comprehensive analysis of the existing literature that specifically examines EV technology and operations. The main focus is on various factors connected to charging, which will be discussed in detail in the following sections.

A. EV CLASSIFICATION

Electric vehicles encompass all forms of vehicles that utilize electricity, either entirely or partially, for their propulsion. All-electric cars (AEVs) and hybrid electric vehicles (HEVs) are commonly categorized based on their energy source and energy management system [13], [14], [15]. AEVs encompass both battery electric cars (BEVs) and fuel cell electric vehicles (FCEVs). Plug-in hybrid electric vehicles (PEHVs) are a type of HEV that utilize both an electric motor and an internal combustion engine to generate power for the wheels. Additionally, PEHVs have the capability to be connected to the power grid for recharging. This study restricts the definition of electric cars to just include BEVs and PEHVs, which will be referred to as EVs for the sake of conciseness.

To learn about EV hardware technologies, we recommend consulting the detailed reviews offered in [16], [17] as this topic is not within the focus of our work.

B. CHARGING MODES AND STANDARDS

EV charging modes are classified according to the type of power source (AC or DC), the power level, and the charging characteristics. Two primary standards govern these classifications: the Society of Automotive Engineers (SAE) J1772 standard, predominantly used in North America, and the International Electrotechnical Commission (IEC) 61851 standard, which is widely adopted in Europe and other parts of the world. A detailed comparison between these standards is essential for understanding their application and the differences in EV infrastructure requirements.

The SAE J1772 standard classifies charging into three levels [18]:

Level 1: This is typically used for residential charging and involves a 120 V single-phase AC supply with a power rating of up to 1.9 kW. Charging times are longer, often taking up to 11 hours to fully charge a vehicle, making it suitable for overnight charging at home [19], [20], [21].

Level 2: Commonly found in both residential and public settings, this level uses a 208-240 V AC supply and offers power levels between 2.5 kW and 19.2 kW. Level 2 charging is faster, with a typical charging time of 4-8 hours, and is well-suited for commercial establishments, workplaces, and public parking spaces [22], [23], [24], [25].

Level 3 (DC Fast Charging): This level bypasses the onboard charger and provides direct DC power to the battery, significantly reducing charging times to under an hour. The power output can reach up to 240 kW, making it ideal for highway charging stations and scenarios where rapid charging is essential [26].

The summary of charging levels in SAEJ1772 is summarized in Table I. On the other hand, IEC 61851 standard categorizes charging into four modes [27], [28] and it is given in Table II:

Mode 1: This mode uses a standard household outlet (230 V single-phase or 480 V three-phase AC) with a maximum current of 16 A and a power output up to 3.7 kW. It is primarily used for slow, overnight charging without any communication between the vehicle and the charging station, making it the most basic charging method.

Mode 2: Similar to Mode 1, but with additional safety features such as in-cable control and protective devices. The power output ranges from 3.7 kW to 7.4 kW, and it is used in residential and light commercial applications.

Mode 3: This mode involves dedicated EV supply equipment (EVSE) with enhanced communication between the EV and the charger. The power output can range from 3.7 kW to 43 kW, making it suitable for semi-fast charging in public spaces and commercial establishments. Mode 3 is analogous to SAE Level 2 but offers a broader range of power levels and typically involves three-phase power.

Mode 4: This mode is equivalent to SAE Level 3 (DC Fast Charging) and provides direct DC power to the EV battery, with power levels exceeding 150 kW. Mode 4 charging is designed for fast charging stations and supports the rapid replenishment of EV batteries in under an hour.

TABLE I
CHARGING LEVELS-SAE J1772

	Supply Configuration	Charger	Supply Type	Rated Current	Rated Power
Level 1	Household outlet	On-board	120 V, Single Phase, AC	12-16 A	1.9 kW
Level 2	Household outlet or EVSE	On-board	208-240 V, Single Phase, AC 12-80 A 2.5-19.2 kW Three phase, AC	12-80 A (Typ. 30 A)	2.5-19.2 kW (Typ. 7 kW)
Level 3	DC connector DC fast charging	Off-board By-passed	208-600 V, Three phase, AC	400 A (Typ. 60 A)	Up to 240 kW (Typ. 50 kW)

TABLE II
CHARGING MODES-IEC61851-1

	Supply Configuration	Charger	Supply Type	Rated Current	Rated Power
Mode 1	Household outlet	On-board	230 V, Single Phase, AC 480 V, Three Phase, AC	Less than 16A	3.7 kW
Mode 2	Household outlet/Industrial Outlet	On-board	230 V, Single Phase, AC 480 V, Three Phase, AC	16-32 A	3.7-7.4 kW
Mode 3	Dedicated EVSE "Semi-Fast" Charging	On-board	230 V, Single Phase, AC 480 V, Three Phase, AC	32 A, 63 A upto 70 A	3.7-43 kW
Mode 4	Dedicated EVSE through DC connector	Off-board	DC Charging 200-1000 V	Up to 200 A	Over 150 kW

Key Differences and Comparisons:

Power Supply and Infrastructure: SAE levels primarily focus on North American power supply standards, with Level 1 using 120 V AC, while IEC modes accommodate both single-phase and three-phase AC supplies commonly found in Europe and other regions. Mode 3 and Mode 4 in IEC offer a more flexible range of power outputs, catering to different charging needs from residential to high-speed commercial applications.

Safety and Communication: IEC standards place a stronger emphasis on communication and safety features, particularly in Modes 2 and 3, where in-cable protection and EVSE communication are required. These features are designed to enhance user safety and optimize charging efficiency.

Adoption and Use Cases: SAE standards are predominantly used in North America, where the power infrastructure and consumer behavior favor the classifications outlined in J1772. In contrast, IEC standards are more widely adopted internationally, offering a more diverse range of charging options to meet varying infrastructure capabilities and regulatory requirements.

On-board and off-board charging are types of conductive charging commonly utilized in EV charging. They are known for their robustness and reliability, as they require a physical contact between the EV and the power supply. Inductive charging, on the other hand, eliminates the need for physical contact and instead relies on wireless power transfer (WPT). This method allows for charging at various levels and can deliver power up to 20 kW, with an efficiency of up to 90% as reported in studies [19], [29], [30]. Inductive charging utilizes the principle of mutual induction to transfer power between the supply network and the EV. The setup is more compact compared to conductive charging, as isolation transformers are not always necessary [31]. The literature discusses various techniques of wireless power transfer, including resonant inductive, inductive, capacitive, and low-frequency permanent coupling power transfer. These techniques are analyzed in terms of their efficiency, operating distance, and frequency [32], [33], [34].

C. CHARGING COORDINATION AND CONTROL

The advancements in smart grid communications and control have played a crucial role in the development of various grid-connected EV technologies. These technologies aim to enhance power system operations by effectively managing and controlling EV charging. As a result, they offer promising opportunities for integrating EVs into power grids, benefiting all stakeholders involved. The integration between EVs and the grid can be categorized, in terms of charging coordination and control, into uncoordinated (dumb) charging and coordinated (smart) charging. The haphazard charging occurs regardless of the grid's condition, which can have a detrimental impact on the stability and reliability of the grid, especially when there is a high number of EVs. EV users would plug into the grid as they see fit, without any involvement from aggregators who would manage and oversee the charging demand placed on the grid. Uncoordinated charging can lead to an increased risk of overloading distribution transformers and cables, which in turn can worsen power losses [11], [13]. Through coordinated or smart charging, EV charging can be scheduled to maximize both technical and economic benefits. These charging strategies involve adjusting EV charging patterns, cycles, and operations to align with the constraints and requirements of the power grid, the preferences of EV users, and the availability of renewable energy resources. It promotes the idea of adjusting the charging schedule to align with periods of abundant

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renewable energy generation, allowing for a greater incorporation of renewable sources in the overall power supply. Smart charging offers a range of control options for EV charging, allowing for flexibility in pricing and advanced technical charging alternatives. Therefore, by utilizing smart charging, EVs can help to even out peak demand, fill in gaps in power usage, and contribute to the stability of power grids. Various mechanisms are used in smart charging, such as static, uncontrolled Time-of-use (TOU) tariffs that encourage charging during off-peak periods, basic on/off switching of charging, dynamic unidirectional controlled charging (V1G), more advanced bidirectional controlled charging (V2G), and dynamic pricing with automated control. Refer to Fig. 4 for a summary of these mechanisms. These options are designed to minimize the impact of EV charging load on peak system demand, which helps avoid the need for infrastructure upgrades in generation, transmission,

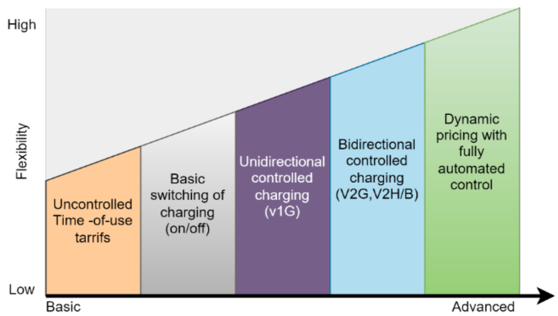

FIGURE 4. Flexibility levels provided by EV smart charging to grid

and distribution [35], [36]. Off-peak charging is a straightforward method of adjusting charging times to coincide with periods of low demand. This approach encourages the use of off-peak charging to alleviate the strain on the power grid and decrease the demand for EVs during peak times [37]. This can be achieved through the use of static off-peak tariffs or by implementing simple end-user programming [3]. Off-peak tariffs can be customized and regularly adjusted to align with the unique market characteristics of a nation or region, taking into account fluctuations in consumption and load profile. Utilizing cost advantages and advanced technology can boost and stimulate increased off-peak EV charging.

EV charging in the unidirectional controlled charging (V1G) method is optimized to align with the grid's constraints and requirements. This is achieved by carefully controlling the timing, rate, and duration of the charging process. This can be achieved by sending signals from utilities or aggregators to EVs/EVSEs in order to control the charging demand and optimize the use of electricity during off-peak periods, thereby reducing peak demand. During unidirectional charging, EVs function as a load for the grid, drawing power from it to charge their batteries. Implementing unidirectional V1G is relatively straightforward and can offer ancillary services such as regulation and spinning reserve [38]. Nevertheless, it is crucial to establish a regulatory framework and energy trading policy that can benefit both the grid operator and EV owner [39]. By utilizing active control, V1G can enhance the proportion of renewable energy generation by aligning charging with optimal periods of solar irradiance and wind-based electricity production. This maximizes the utilization of both solar and wind power. In V1G, aggregators serve as crucial intermediaries, overseeing communications and control functions between all stakeholders involved. They also help alleviate the need for network infrastructure upgrades in terms of control and communication capabilities [3].

Vehicle to grid (V2G) technology, on the other hand, has the potential to revolutionize the energy landscape. It enables a two-way flow of energy between EVs and the grid, transforming EVs into storage systems and power providers rather than just consumers. This active participation allows EVs to actively contribute to peak shaving. Through the utilization of necessary infrastructure for V2G deployment, the grid operator effectively manages the power flow to maximize the benefits of V2G, including improved power quality, reduced emissions, and increased economic profit [11], [40], [41]. With bidirectional EV charging, there is a broader array of ancillary services available and greater flexibility compared to the unidirectional mode. This involves: providing active and reactive power support by managing peak load and ensuring a balanced power supply; optimizing the size of the charger DC link capacitor and implementing efficient switching control; regulating power factor to minimize grid losses; and facilitating the integration of renewable energy by acting as a storage source to address the intermittent nature of renewable energy resources [42], [43], [44]. However, there are other technical challenges that can impact the potential of V2G. One such challenge is the premature battery degradation caused by frequent charging and discharging cycles [45].

D. HARDWARE ADVANCEMENT in EVs

Electric vehicle hardware technology has seen significant advancements in recent years, particularly in areas that directly influence charging efficiency and grid integration. These hardware developments play a critical role in enhancing the performance, reliability, and compatibility of EVs with existing and future power infrastructure.

1. **Battery Technology: Lithium-ion Batteries:** The widespread adoption of lithium-ion batteries has been a key driver of EV growth due to their high energy density, long cycle life, and decreasing costs. Recent advancements include improvements in energy density, which allows for longer driving ranges, and the development of fast-charging capabilities, which reduce charging times significantly [46], [47]. **Solid-state**

Batteries: Emerging as a promising alternative, solid-state batteries offer higher energy densities, faster charging, and improved safety compared to conventional lithium-ion batteries. While still in the research and development stage, they have the potential to revolutionize the EV market by addressing key limitations of current battery technologies [48].

2. **Charging Infrastructure: DC Fast Chargers:** Hardware advancements in direct current (DC) fast chargers have significantly reduced charging times, making EVs more convenient for long-distance travel. These chargers can deliver high power levels (up to 350 kW) and are increasingly being integrated into public charging networks [49], [50] . **Bidirectional Chargers:** These chargers, essential for V2G applications, allow energy to flow both from the grid to the vehicle and from the vehicle back to the grid. This capability is crucial for smart charging strategies, enabling EVs to act as mobile energy storage units that can support grid stability and renewable energy integration [51].
3. **Power Electronics: Onboard Chargers:** Modern onboard chargers have become more efficient and compact, allowing for faster AC charging and reducing energy losses during the charging process. Innovations in power electronics, such as silicon carbide (SiC) and gallium nitride (GaN) semiconductors, have further improved the efficiency and thermal performance of these chargers [52], [53] . **Inverters:** Inverters, which convert DC from the battery to AC for the motor, have also seen significant advancements. The use of SiC and GaN technologies in inverters has resulted in higher efficiency, reduced size and weight, and improved thermal management, contributing to better overall vehicle performance and extended range [54].
4. **Thermal Management Systems:** As power density in batteries and power electronics increases, effective thermal management has become crucial. Advanced cooling systems, including liquid cooling and phase-change materials, are now being integrated into EVs to maintain optimal operating temperatures, thereby enhancing safety, performance, and longevity of components [55].
5. **Wireless Charging:** Wireless or inductive charging is an emerging technology that allows for convenient, cable-free charging. While currently less efficient than wired methods, advancements are being made to improve the power transfer efficiency and range of these systems.

Wireless charging has the potential to simplify the charging process, particularly in urban environments and for autonomous vehicles [56].

Understanding the operations of EVs, including their classification and the charging modes they employ, is crucial not only for improving their efficiency and user experience but also for comprehending their broader impact on the energy systems they interact with. As EV adoption increases, these operational factors play a significant role in shaping how these vehicles interface with power grids, ultimately influencing the stability, reliability, and efficiency of electricity distribution networks.

Given the operational intricacies of EVs, their integration into existing power grids presents both opportunities and challenges. As EVs become more prevalent, their impact on power grid dynamics grows increasingly significant. The manner in which EVs charge, discharge, and interact with the grid can lead to substantial implications for grid stability, power quality, and infrastructure resilience. Therefore, it is essential to explore these impacts in greater detail to understand the potential benefits and challenges of widespread EV adoption on power systems.

III. IMPACT ON POWER GRID

The impact of EVs on power grids has become a critical area of study as the number of EVs continues to rise. The load profiles of EVs, their charging behavior, and the associated power quality issues such as harmonics, voltage imbalances, and grid asset stress are central concerns that need to be addressed to ensure a smooth integration of EVs into power systems. The power consumption of EVs can be influenced by factors such as the battery capacity, driving characteristics, and the specific car model. However, the charging demand is influenced by various factors and can vary based on the battery's chemistry, state of charge, supply voltage, number of phases, drawn current, charging mechanism, and its connection to the grid for energy tapping and/or providing additional services [57]. Furthermore, the integration of EVs into power systems poses several challenges, particularly concerning power quality issues such as harmonics, which can affect the stability and reliability of the grid. Harmonics are distortions in the voltage and current waveforms caused by non-linear loads, such as EV chargers. These distortions are typically quantified using Total Harmonic Distortion (THD), which is a measure of the cumulative effect of all harmonic components relative to the fundamental frequency.

The THD for voltage (THD_V) and current (THD_I) are given by the following formulas:

$$THD_V = \frac{\sqrt{V_2^2+V_3^2+V_4^2+\cdots+V_n^2}}{V_1} \text{ x } 100\% \tag{1}$$

$$THD_I = \frac{\sqrt{I_2^2+I_3^2+I_4^2+\cdots+I_n^2}}{I_1} \text{ x } 100\% \tag{2}$$

Where V_1 and I_1 represent the RMS values of the fundamental frequency components of voltage and current, respectively, and $V_2, I_2, \ldots, V_n, I_n$ are the RMS values of their harmonic components. High THD values indicate significant distortion, which can lead to inefficiencies, overheating, and potential damage to grid infrastructure. Managing and mitigating THD is therefore critical in ensuring the smooth integration of EVs into power systems [58].

In this section, we present a summary of studies that have examined the effects of EVs on the electric grid. Initially, we examine scholarly articles that have examined the influence of EVs on the electric grid in relation to their load profile. Next, we redirect our attention towards identifying research that have examined the capacity of EVs to facilitate the integration of renewable energy sources into the power grid. Next, we provide a concise overview of initiatives that addressed several technical concerns linked to EVs, such as their impact on the stability of the electrical grid, power loss, the injection of harmonics, voltage and phase imbalances, and the impact on grid assets.

A. LOAD PROFILE

The widespread adoption of EVs poses issues to electricity systems. The introduction of additional loads at peak periods, caused by the charging and discharging behavior, is a significant concern. This further complicates the ongoing efforts to balance supply and demand, especially in cases when charging is not coordinated [57], [59], [60]. Multiple studies have examined the effect of integrating EVs into various national power networks on the demand profile [61]. Studies conducted in countries such as Germany and Korea have indicated that the load profile may be artificially increased, leading to a detrimental effect on the grid's reliability. Therefore, this necessitates further investment in both the transmission and generation sectors [62], [63]. An analysis was conducted to hypothetically assess the impact of EV charging on peak load. The objective was to compare the maximum potential peak load resulting from the integration of EV loads [64]. The study examined the possible effect on the baseline peak load in each country for different levels of EV adoption, expressed as a percentage of households who own EVs. The analysis explored several charging capacity levels, including 2 kW, 4 kW, 20 kW, and 40 kW. It was presumed that all EV loads are linked to the grid during the period when the grid reaches its highest demand of the year. Table III [64] demonstrates a significant disparity in the preparedness of power networks to handle the increasing demand for EV charging. The power grids in the United States and Europe are better equipped to meet this demand compared to China.

Existing literature frequently highlights how EV charging increases peak demand, potentially destabilizing the power grid without smart management solutions. Studies often emphasize the technical challenges but less so on practical, scalable solutions. Moreover, the reliance on assumptions about charging behavior and the availability of renewable energy integration leaves a gap in addressing real-world variabilities and consumer behavior unpredictability. We propose that future research should focus more on developing adaptive smart grid technologies that can dynamically respond to changes in EV charging demand. There is a need for more robust data analytics that can predict charging behaviors based on real-time data rather than static models. Also, integrating AI and machine learning could refine load forecasting methods, enhancing grid stability.

Furthermore, to ensure a comprehensive understanding of load profile, it is essential to consider future technological advancements in both EVs and grid infrastructure that could alter these impacts.

Increased Energy Density: Future advancements in battery technology, such as solid-state batteries, are expected to offer higher energy densities, leading to longer driving ranges. This could result in less frequent charging, thereby smoothing out demand spikes and reducing the impact on the load profile.

Faster Charging Capabilities: As batteries become capable of faster charging, the demand for high-power, short-duration charging will increase. While this could create new peak demands, it also presents an opportunity to align charging with periods of renewable energy surplus, thereby mitigating potential negative impacts on the grid.

Efficient Inverters and Chargers: The adoption of silicon carbide (SiC) and gallium nitride (GaN) technologies in power electronics will improve the efficiency of inverters and onboard chargers. These advancements reduce energy losses during conversion and charging, which can help stabilize the grid by minimizing unnecessary demand spikes.

Bidirectional Charging: V2G technology allows EVs to return electricity to the grid, providing a form of distributed energy storage. This capability can help balance load profiles by absorbing excess generation during low-demand periods and discharging during peak demand, thus reducing strain on grid infrastructure.

Dynamic Load Management: Future smart grid technologies will likely incorporate more sophisticated load management systems that can dynamically adjust to real-time demand and supply conditions. This includes more effective demand response programs and the integration of AI-driven predictive analytics to forecast and manage EV charging patterns more accurately.

Grid Modernization: Investments in grid modernization, including the deployment of advanced metering infrastructure (AMI) and enhanced communication networks, will enable better monitoring and control of EV loads. This will help mitigate the potential negative impacts of EV charging on the load profile, particularly in regions with high penetration rates.

Renewable Energy Alignment: The increasing share of renewable energy in the grid, coupled with advancements in energy storage, will influence the load profile by providing more opportunities for off-peak EV charging. For example, smart charging strategies can align EV charging times with periods of high renewable generation, such as midday solar peaks, to reduce reliance on non-renewable generation and smooth out the load profile.

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Distributed Energy Resources (DERs): The growth of distributed energy resources, including residential solar panels and local energy storage, will provide additional flexibility to the grid. This can help absorb local EV charging loads and reduce the burden on central generation and transmission systems, thereby stabilizing the overall load profile.

As these technological advancements and infrastructure developments continue to evolve, the influence of EVs on the load profile is likely to become more manageable. While high penetration rates of EVs could initially exacerbate peak demands and stress the grid, the strategic deployment of V2G technology, smart charging, and grid modernization efforts will play a crucial role in mitigating these effects. Therefore, any assessment of the impact of EV integration on the load profile must consider these future developments to provide a more accurate and forward-looking analysis.

TABLE III
EV CHARGING IMPACT ON PEAK LOAD AT DIFFERENT PENETRATION LEVELS

	Charging Capacity Levels	Germany	Denmark	France	California	China
1% Penetration Level	2kW	1.00%	0.80%	0.60%	0.50%	1.30%
	4kW	1.90%	1.60%	1.10%	1.10%	2.60%
	20kW	9.70%	8.10%	5.50%	5.40%	13.20%
	40kW	19.50%	16.30%	11.10%	10.70%	26.30%
3% Penetration Level	2kW	2.90%	2.40%	1.70%	1.60%	4.00%
	4kW	5.80%	4.90%	3.30%	3.20%	7.90%
	20kW	29.20%	24.40%	16.60%	16.10%	39.50%
	40kW	58.40%	48.90%	33.20%	32.20%	79.00%
5% Penetration Level	2kW	4.90%	4.10%	2.80%	2.70%	6.60%
	4kW	9.70%	8.10%	5.50%	5.40%	13.20%
	20kW	48.70%	40.70%	27.70%	26.80%	65.80%
	40kW	97.30%	81.50%	55.40%	53.60%	131.70%
7% Penetration Level	2kW	6.80%	5.70%	3.90%	3.80%	9.20%
	4kW	13.60%	11.40%	7.70%	7.50%	18.40%
	20kW	68.10%	57.00%	38.70%	37.60%	92.20%
	40kW	136.30%	114.10%	77.50%	75.10%	184.40%

B. RENEWABLE ENERGY

Multiple studies indicate that EVs can effectively assist in integrating renewable resources into the grid and mitigating their intermittent nature over time. This addresses a persistent difficulty encountered by utility firms. Research indicates that EVs, with their efficient power electronics converters and storage technology, can support the integration of renewable energy sources into the power grid. This integration of renewables can help mitigate any negative effects that EVs may have on the grid [65]. The integration of smart scheduling of EV charging with renewable energy, using a rolling horizon approach, indicates that it is possible to lower the annual demand on the grid without making major changes to the peak demand requirements [66].

The scheduling of EV charging can help in effectively regulating and reducing the duck curve, which is created by the mismatch between high power demand and renewable energy generation [67]. With the growing reliance on renewable energy sources such as solar power to meet the rising power demand, the conventional load curve, as shown in Fig. 5, undergoes a distinct transformation.

Grid operators are confronted with the need to swiftly take power plants offline and bring them back online, which imposes additional ramping requirements. This has a detrimental impact on the flexibility, dependability, and maintenance cost of the grid. A digital model was suggested for intelligent scheduling of EV chargers, which reduces the need for rapid power adjustments and minimizes the chances of excessive power generation [68].

While the benefits of integrating EVs with renewable energy sources are well documented, the practical aspects of such integration at scale remain underexplored. Most studies provide a theoretical framework without addressing the economic and regulatory hurdles that hinder widespread adoption. Our analysis suggests a multi-stakeholder approach is crucial, involving policymakers, energy providers, and technology developers. Incentives should be aligned to promote not just EV adoption but also the establishment of renewable-powered charging stations. Additionally, innovations in battery technology that allow for faster charging during renewable peak production times could align EV charging demands with renewable energy availability.

C. GRID STABILITY

Refers to the ability of an electrical grid to provide a steady and reliable supply of electricity without experiencing disruptions or fluctuations. The integration of a large number of EVs into the power grid primarily results in a temporary deviation from its normal functioning and impacts its vulnerability to disruptions and the duration required to return to stable conditions [69]. Unregulated EV charging can cause instability in distribution networks by overloading them, leading to congestion [70]. An analysis of voltage stability was conducted to assess the influence of EVs on the steady-state voltage stability of the power grid. This was achieved by creating models of rapid charging stations and considering the unique characteristics of EV load. The study determined that the specifications of EV chargers have an impact on the system loading margin in various scenarios [71]. However, the effect on stability is still uncertain and requires additional exploration. For instance, when EVs are connected to the power grid, their integration improves the stability of the grid [72]. A simulation research performed on the IEEE RTS-96 24 bus system discovered that the integration of EVs had a positive impact on the Short-Term Voltage Stability Index (SVSI). The improvement was

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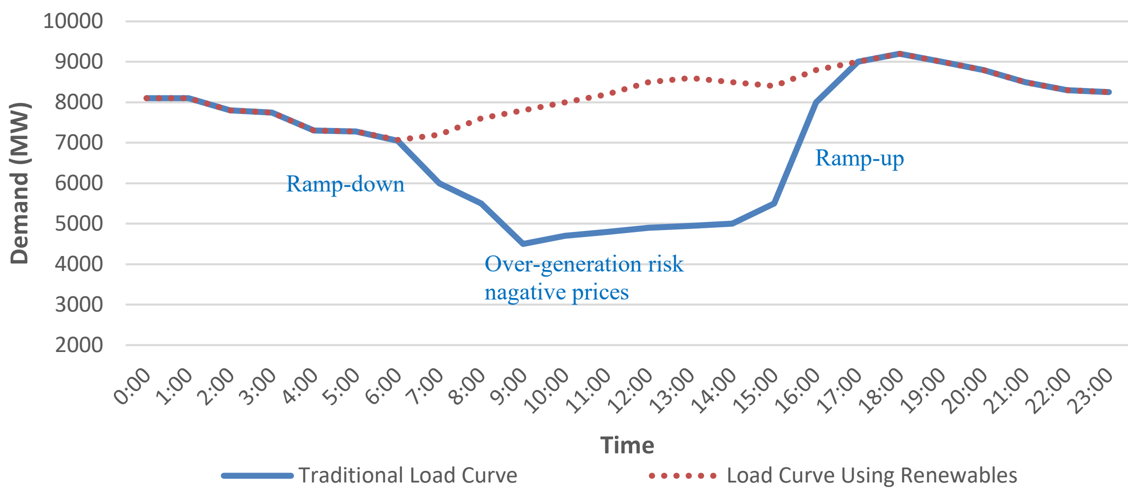

FIGURE 5. **A typical duck curve**

dependent on the aggregated connected load and the specific location (load bus) where the EVs were connected [73]. On the other hand, the effect on the stability of the power grid was examined using the IEEE 33 bus network. The installation of rapid chargers at vulnerable buses resulted in a drop in voltage stability [74].

The integration of EVs into the power grid introduces challenges such as phase unbalance and overload, particularly as EV adoption increases. These issues can lead to inefficiencies, increased power losses, and potential damage to grid infrastructure. To address these challenges, several strategies have been developed and are being implemented to ensure stable grid operations.

Smart Charging and Load Management: Smart charging involves controlling the time and rate of EV charging to align with grid conditions and avoid peak demand periods. This strategy can reduce the risk of overload and help balance the load across the three phases of the grid. At low levels of EV penetration, smart charging can effectively distribute the charging load, minimizing the risk of phase unbalance. The impact on the grid is generally manageable, and existing infrastructure can accommodate the additional load with minimal modifications. As EV adoption increases, the effectiveness of smart charging becomes more critical. Advanced algorithms that optimize charging schedules based on real-time grid conditions and forecasts are required to prevent overload and maintain phase balance. However, in grids with limited flexibility or outdated infrastructure, the benefits of smart charging may be reduced, necessitating further grid upgrades [75].

Phase Balancing Algorithms: Phase balancing algorithms are used to dynamically adjust the load on each phase by switching the charging phases of EVs. These algorithms can be implemented in charging stations to ensure that the load is evenly distributed across all three phases. In grids with well-maintained infrastructure and moderate EV penetration, phase balancing algorithms can maintain a stable and balanced load, preventing phase unbalance from becoming a significant issue [76].

Vehicle-to-Grid (V2G) Technology: V2G technology allows EVs to discharge electricity back to the grid, providing a means to balance supply and demand dynamically. V2G can be used to support phase balancing by directing energy to underutilized phases or alleviating overloads by discharging during peak periods. In grids with low to moderate EV adoption, V2G can effectively mitigate both phase unbalance and overload by acting as a distributed energy resource. The grid benefits from enhanced flexibility and reduced peak loads. At high levels of EV adoption, the effectiveness of V2G depends on widespread participation and sophisticated coordination between EVs and the grid. While V2G can provide significant benefits, its implementation is complex, requiring robust communication infrastructure and incentives for EV owners to participate [77].

Distributed Energy Resources (DERs): Integrating distributed energy resources, such as rooftop solar panels and local energy storage systems, can help alleviate phase unbalance and overload by providing additional local generation and load balancing capabilities. In localized grids or microgrids, DERs can significantly enhance phase balance and reduce the risk of overload by providing supplementary power during peak demand periods. This is especially effective when coupled with smart inverters that can control the flow of energy across phases. In larger, wide-area grids, the impact of DERs on phase balance and overload is more dispersed but still beneficial. The key to maximizing their effectiveness lies in the integration of DERs with advanced grid management systems that can coordinate their output in real time [78], [79].

D. POWER LOSS

The integration of EVs into the power grid has a significant impact on power losses, particularly as the penetration levels of EVs increase. The magnitude of these losses is influenced by several factors, including the level of EV penetration, the charging power level, and the charging strategies employed. As EV penetration increases, the total power demand on the grid rises correspondingly, leading to higher distribution losses. Studies have shown that at low penetration levels (e.g., 1-5% of the total vehicle fleet), the impact on power losses is relatively moderate. However, as penetration levels reach 20% or more, the losses can increase significantly. For instance, at a 20% penetration level with uncoordinated charging, power losses can rise by approximately 40%, depending on the charging power and the grids capacity to handle the additional load [74], [80], [81]. Different charging scenarios further exacerbate or mitigate these losses:

Uncoordinated Charging: This scenario, where EVs are charged as soon as they are plugged in without any consideration for the grid's load conditions, typically leads to the highest power losses. The simultaneous charging of multiple EVs during peak hours can create severe stress on the grid, leading to congestion and increased losses in distribution lines.

Off-Peak Charging: Encouraging EV charging during off-peak hours can help reduce peak demand and associated losses. However, if a large number of EVs charge simultaneously during off-peak periods, significant power losses can still occur, especially in areas with limited grid infrastructure.

Smart Charging (V1G): This scenario involves controlled charging where the timing, rate, and duration of EV charging are optimized to align with grid conditions and renewable energy availability. Smart charging can significantly reduce power losses by distributing the load more evenly and avoiding peak demand periods. Studies have shown that implementing smart charging can reduce power losses by up to 10% compared to uncoordinated charging.

Vehicle-to-Grid (V2G) Charging: V2G technology allows for bidirectional energy flow, where EVs can discharge power back to the grid. This scenario can help balance supply and demand, particularly during peak periods, and reduce the need for additional generation capacity. However, the complexity of managing V2G operations and the potential wear and tear on EV batteries must be considered.

The increase in power losses due to high EV penetration levels and varying charging scenarios necessitates upgrades in grid infrastructure. Without appropriate investments in transmission and distribution networks, the rising power losses could lead to reduced grid reliability, increased operational costs, and potential service disruptions.

In conclusion, a comprehensive assessment of power losses must consider not only the level of EV penetration but also the specific charging scenarios in place. By adopting smart charging strategies and making necessary grid upgrades, it is possible to mitigate the negative impacts of EV integration on power losses and ensure a more stable and efficient power system [82].

E. HARMONICS INJECTION

The power electronics in EV chargers play a crucial role in determining the harmonics that are introduced into the power grid during the process of power conversion. This can result in harmonic distortion and other power quality problems for the grid, as well as potentially overloading distribution assets and reducing their lifespan [22]. Prior research indicated that the rise in total harmonic distortion (THD) resulting from residential single-phase loads and EV charging was not excessive and should not be worrisome [83]. This claim was further supported by a subsequent study that took into account the dynamic aspects of EV charging, such as the variability in charging time, duration, and locations [84]. However, a different study indicated that Level 1 chargers can elevate the neutral to earth voltage, increasing the probability of stray voltage incidents. EV rapid chargers can have a substantial effect on the power system by introducing high harmonic currents that can cause voltage distortion above acceptable limits [85]. A simulation was conducted to evaluate the effectiveness of using PV inverter control to reduce harmonic injections resulting from fast charging. The simulation findings demonstrated a decrease in total harmonic distortion (THD) for both current and voltage [85].

F. VOLTAGE AND PHASE IMBALANCE

The power delivered to customers can be impacted by voltage drop and voltage deviation at the point where the EV grid connects [86]. When there are many EVs linked to the grid, there is a possibility that the voltage needs may not be met, resulting in a voltage drop that exceeds the permitted limit. An examination was conducted to investigate the impact of charging load on the grid [87]. The analysis considered various charging strategies and found that uncoordinated charging at high penetration levels exceeded the acceptable voltage limits, unlike in the case of V2G charging where the voltage remained within acceptable limits up to a penetration level of 50%. Furthermore, EV chargers can contribute to the issue of phase unbalance, particularly in the context of single phase slow residential charging. This occurs when the loads are not equally spread throughout the phases, which might impede the expansion of EV charger installations [80].

G. GRID ASSETS

The constraints on the physical components of distribution grids are examined in relation to the integration of EVs and their influence on the overall performance. The surge in energy usage resulting from the demand for EV charging often exceeds the capacity of the network components, leading to overload. The increased prevalence of EVs is commonly linked to thermal overloading, reduced lifespan of assets, and aging. A study examining the impact of AC level 1 and level 2 chargers on the aging of distribution transformers discovered that the aging factor of the transformers was more than double for level 2 chargers compared to level 1 chargers [88]. A separate study examined the effects of disorganized EV charging on the cables' ability to carry electricity. The study discovered that under typical charging conditions, a cable can handle up to 25% of EVs being connected. However, in fast charging situations, the cable's capacity is limited to only 15%, which restricts the ability to accommodate higher levels of EV usage [89].

While the integration of EVs into the power grid presents both opportunities and challenges, the success of this integration hinges on widespread adoption. The following section will examine the factors influencing EV adoption, exploring the drivers, barriers, and strategies that can accelerate the shift towards electric mobility.

IV. ADOPTION OF ELECTRIC VEHICLES

The fluctuation in gasoline costs, the escalating levels of greenhouse gas emissions globally, and the growing reliance on imported petroleum by certain nations are all instances of external factors that enhance the attractiveness of the EV market to both people and societies as a whole. Multiple studies have conducted a literature review on the significance of these characteristics, as well as other internal factors like driving range and charging time, in connection to the adoption of EVs [90] . The advantages of EV adoption extend beyond being a more environmentally friendly mode of transportation. As previously said, EVs can help incorporate Renewable Energy Sources (RES) into the power grid by offering energy storage services for the intermittent and fluctuating RES [91].

This section provides a comprehensive analysis of the literature that has identified and examined several factors that influence the adoption of EV on a global scale, as presented in Fig. 6.

The objective is to furnish the reader with a concise overview of the primary motivating elements and obstacles that can offer direction when formulating policies and transitioning plans to EVs for a more environmentally friendly transportation system. We offer a comprehensive analysis of current methodologies and their capacity to stimulate the adoption of EVs. We additionally document the solutions implemented by various EV marketplaces in response to their specific contextual circumstances. Furthermore, we review scientific publications that suggest frameworks for addressing the challenge of raising EV adoption rates.

A. ECONOMIC VIABILITY

To assess the economic feasibility of EVs for customers, various studies have examined the various components of the Total Cost of Ownership (TCO) framework. These components include the cost of purchase, maintenance, operating, depreciation, and energy costs [92]. Several evaluations have been conducted to determine the influence of the total cost of ownership on the adoption of EVs. A comparative analysis was conducted to examine the fiscal incentives in various nations and their influence on the overall cost of ownership and sales of EVs [93]. In Norway, the incentives resulted in the most favorable Total Cost of Ownership (TCO) for EVs compared to numerous other European countries. Therefore, the significant upfront expense of EVs is seen as a discouraging factor for potential early adopters [94]. Another factor that raises doubts about the overall economic feasibility of EVs is the accessibility of downstream maintenance, service, and repair, which has produced confusion among customers. Additionally, it is important to consider whether the higher initial purchase prices of EVs would be balanced out by the reduced operating costs. Therefore, creating a sense of a lengthy repayment period that has a negative impact on client demand and presents an additional impediment [95].

B. CHARGING INFRASTRUCTURE

Progress in EV technology has made significant strides. However, a significant issue that still has to be addressed is the driving range of EVs. The battery range of an EV is the maximum distance it can travel before requiring a recharge. In order to achieve widespread and lasting adoption of EV, it is crucial to have a robust and interconnected charging infrastructure network.

The International Council on Clean Transport (ICCT) releases yearly reports that examine strategies employed in the most significant EV markets. These reports serve as a reference for other nations seeking guidance in their own EV

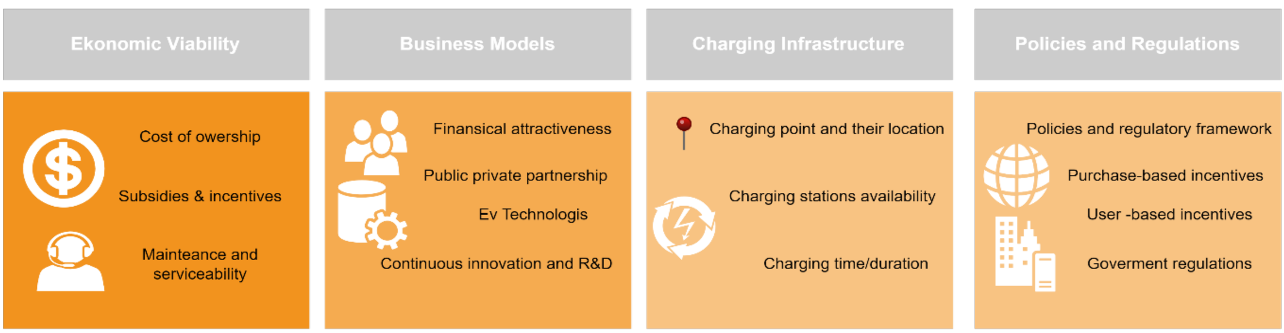

FIGURE 6. **Overview of key elements influencing the global adoption of EVs**

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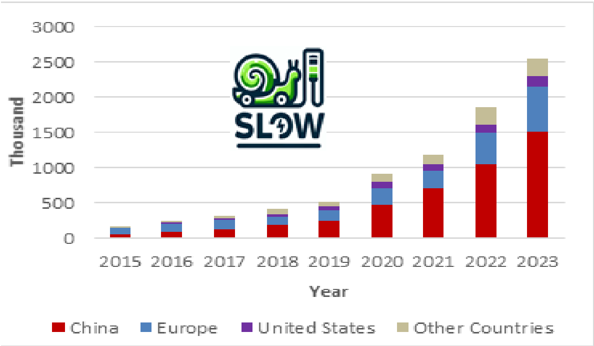
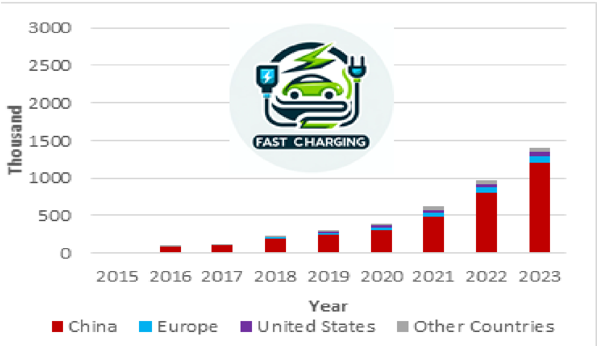
transition plans. Multiple briefings have indicated a statistical correlation between the extent of EV adoption and the availability of charging infrastructure [96], [97], [98], [99]. The correlation, however, is contingent upon demographic variables such as urban density, as well as charging-related behaviors. Fig. 7 illustrates the distribution of publicly installed accessible slow (Fig. 7-a) and fast charging (Fig. 7-b) stations in relation to each other and to the charging points in different locations [3].



(a)



(b)

FIGURE 7. **Charging station distribution by country a-Slow Charging b-Fast Charging**

China is currently in the forefront of implementing public charging infrastructure. Shenzhen alone possesses a greater number of public charging points than the combined total of the major EV capitals in Europe and the United States [99].

This phenomenon could potentially be attributed to the significant population density in China. Even when accounting for population size, Shenzhen remains in the forefront with 4000 public charging outlets per 1 million residents. Oslo and Amsterdam follow closely with approximately 3500 public charging points per million citizens each. Oslo has a significantly greater ratio of EVs to public charging points compared to places like Shenzhen, Amsterdam, London, and Tokyo. In Oslo, there are approximately 25 EVs for every public charging station, whereas in the other cities, the ratio is around 10 EVs per public charging point. This graph suggests that the rate at which EVs are being adopted in certain cities is surpassing the pace of infrastructure construction for these vehicles. It may also indicate that certain cities have a greater dependence on private charging stations located at residences and workplaces.

Turning our attention to Norway, the foremost nation in embracing EVs and providing incentives for BEVs specifically, an evaluation was conducted to determine the impact of these incentives on the spread of EVs. This evaluation analyzed the sales of EVs at both a regional and municipal level [100]. Another endeavor was to determine the characteristics that ensure a greater dissemination of EVs, including local demographic data and incentive measures. According to the authors' findings, the availability of charging stations had the greatest impact on the number of EV sales per person. They also observed that a lack of charging infrastructure decreased the flexibility and convenience for users, making EVs less appealing [101]. Travel range anxiety and battery durability are significant obstacles to the widespread adoption of EVs in relation to charging infrastructure [102]. The phenomenon of range anxiety is closely associated with the accessibility of charging stations and can significantly impact the overall experience of EV users [103]. The negative view of EV technology as inferior and unreliable is influenced by both its short driving range and lengthy charging time. This concept could potentially result in EV owners limiting the use of their vehicles to shorter trips, viewing EVs as secondary vehicles [104].

The balance between public and private charging infrastructure affects overall EV adoption in several ways:

Accessibility: A well-distributed network of public charging stations increases the accessibility of EVs for users without private charging options, thereby expanding the potential market for EVs.

User Confidence: The presence of public charging infrastructure reduces range anxiety and builds user confidence in the reliability of EVs as a primary mode of transportation.

Convenience: While private charging offers convenience for regular users, public charging infrastructure provides the necessary support for long-distance travel and for users in urban environments where private charging may not be feasible.

In summary, a balanced approach that includes both public and private charging infrastructure is essential to maximizing EV adoption and ensuring user convenience. Policymakers and industry stakeholders should focus on expanding public charging networks while also encouraging the installation of private charging stations in residential and commercial buildings to support a diverse range of EV users.

Furthermore, the literature extensively discusses the need for advanced charging infrastructure to support the growing number of EVs. However, there is a significant lag in developing and deploying these technologies at a pace that matches EV adoption rates. Investment in R&D for high-efficiency, fast-charging stations is critical. The development of universal charging standards that can operate seamlessly across different regions and EV models would facilitate broader adoption. Public-private partnerships could be pivotal in rolling out the necessary infrastructure rapidly and efficiently.

C. POLICIES AND REGULATIONS

Regulations and policies can be categorized into three types: purchase-based incentives, use-based incentives, and regulatory policies, as outlined in Table IV [12].

Acquisition-oriented incentive schemes encompass direct subsidies provided for EV purchases, registration fees, tax costs, and similar expenses. These regulations are enacted to decrease the cost of purchasing. An investigation was conducted to examine the correlation between financial incentives and the market share of EVs in 20 nations. According to the authors, the presence of a financial incentive plays a crucial role in encouraging the adoption of EVs [105]. Use-based incentive policies are specifically tailored to benefit EV users. These policies include perks such as free parking and toll tax exemption, among others. The study revealed that incentives such as complimentary parking, unrestricted access to bus lanes, and exemption from toll costs had a crucial role in the widespread adoption of EVs [106]. The government laws are the result of choices made at the national level to promote and support the electrification of the transport fleet [107].

Government restrictions might be implemented to bolster Original Equipment Manufacturers (OEM), dealership, and fuel suppliers in order to streamline the sales of EVs. The regulatory framework can also be structured to incorporate more stringent limits on CO_2 emissions and promote the use of cleaner engine technologies, as exemplified by Europe's aim of 95 grams of CO_2 emissions per fleet. The European Union has introduced a new regulation stating that by 2021, all passenger automobiles must adhere to the performance criterion of emitting no more than 95 grams of carbon dioxide per kilometer [108].

D. BUSINESS MODELS

Although the EV markets are growing quickly, they are still relatively underdeveloped, with performance differing between countries and regions. Additionally, none of the markets have reached the popular level needed to transition from a niche category. Within the developing EV ecosystem, a business model outlines the methods for generating and acquiring value from EVs, ultimately resulting in increased technology adoption and market expansion. A business model typically consists of the value proposition, target market, and cost and revenue streams [109]. The business models in the EV industry vary widely in terms of the services they offer, such as implementation, financing, maintenance, and others. These models aim to increase the adoption of EVs and overcome the constraints mentioned previously [110]. These limitations encompass factors such as exorbitant expenses, restricted driving distance, lengthy recharge duration, limited infrastructure availability, absence of standardized protocols and regulations, and battery capacity, among other obstacles.

Business models can be classified based on their ability to address the obstacles to EV adoption. Multiple studies have examined EV business models in the existing body of literature. These studies have revealed common trends and patterns among the EV sector, as illustrated in Figure 8 [111], [112],[113], [114],[115].

A prominent illustration is the widely embraced EV sharing initiative, wherein individuals have the opportunity to lease automobiles from a flexible fleet for brief durations. The benefits of such programs are manifold, including more flexibility, heightened public awareness, and, most crucially, alleviating potential customers from the obstacle of purchase cost by prioritizing usage rather than ownership. Furthermore, EV sharing programs are becoming increasingly popular in urban areas where the density of population and short commuting distances make this model viable. Such programs reduce the need for ownership by offering access to EVs for short periods, which is appealing in cities with high parking costs and limited parking space. Despite their benefits, these programs face challenges, including the high operational costs associated with fleet maintenance and the logistical complexity of managing numerous pick-up and drop-off points. The success of these programs heavily relies on continuous usage and high turnover rates of vehicles, which may not be sustainable in less populated areas.

TABLE IV
SUMMARY OF EXISTING POLICIES TO INCREASE EV ADOPTION

Policies	Purpose	Targeted group	Examples
Purchase-based incentives	Encourage the purchasing of an EV, typically in a form of subsidized fees.	EV adopters	Tax exemptions or reductions, vehicle registration exemptions or reductions
Use-based incentives	Increase the convenience of EV use.	EV adopters	Free parking, express lane free access, toll exemptions
Regulatory	Facilitate EV sales and adoption.	OEMs, dealerships, suppliers	Maximum emission-per-vehicle mandate, corporate average fuel economy (CAFE)

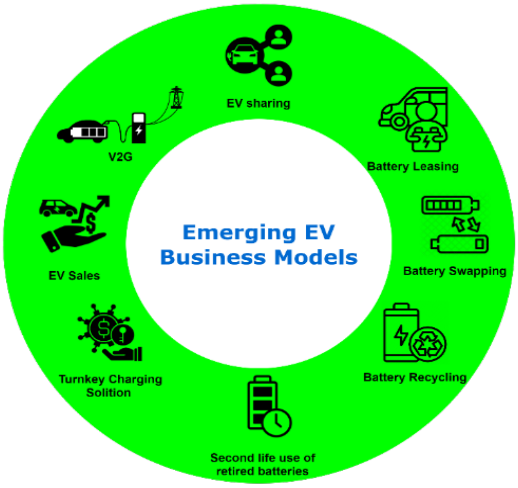


FIGURE 8. EV business models

Some other electric car sharing programs use advanced technology to offer a more comprehensive range of services, from providing vehicles to managing client relationships. These projects align with the growing trend towards Electric Mobility as a Service (EmaaS). Alternative vehicle models that offer unique ownership alternatives, such as battery leasing and battery swapping, are effective in addressing concerns related to the initial purchase cost, range anxiety, resale anxiety, and environmental impact. This model is particularly relevant in markets where the high upfront cost of EVs is a significant barrier to adoption. By separating the vehicle purchase from the battery, consumers can access cheaper and more flexible mobility solutions. The main challenges here involve the logistics of setting up sufficient swapping stations and ensuring compatibility across different models and brands. There's also the risk associated with the residual value of batteries and the technological obsolescence due to rapid advancements in battery technology. Similarly, the charging business models encompass various services such as rapid charging facilities for EV sales, complete solutions for the installation of charging stations, and paid subscriptions for accessing publicly available charging stations, among other options. Charging-as-a-service is a promising model in regions with developing EV infrastructure. This model can cater to apartment dwellers or those without access to home chargers, providing critical charging services through a network of charging stations. Significant investment in infrastructure is required to ensure widespread and reliable access. Moreover, the economic model needs to balance pricing that is affordable for consumers while still being profitable enough to continue expanding the charging network.

Furthermore, V2G business models inside a smart grid setting present an appealing possibility for EV adopters to generate potential income by participating in grid services [114],[116]. In markets with a high penetration of renewable energy sources, V2G services can help stabilize the grid by using EV batteries as temporary energy storage devices to absorb excess energy during low demand and release energy during peak demand. Technical challenges related to battery wear and tear, as well as the need for compatible infrastructure and regulatory frameworks that recognize and compensate EV owners for their contributions to grid stability, are significant hurdles.

The active involvement of stakeholders in the EV ecosystem is essential for effectively using the potential of new EV business models and addressing adoption challenges in the EV sector [112]. This can be achieved through collaborative partnership strategies that span the entire value chain of the EV industry. Ying et. al contended in their study that the business model implemented in Shenzhen, which involved a public-private partnership (PPP) to invest in charging infrastructure, had the potential to serve as a source of inspiration for policymakers in other countries aiming to promote the widespread adoption of EVs [117]. In contrast, Singapore lacks EV incentive measures in its market and is further hindered by car taxation schemes. However, a business model was proposed by [118]. The proposed concept seeks to decrease the initial purchase price of EVs by utilizing a quasi-discount from car dealers' profits, while ensuring that government tax revenues remain unaffected.

Economic models often fail to fully capture the long-term benefits and costs of EV integration into power grids, focusing more on immediate fiscal impacts. Policies are also fragmented, with significant variations between regions, which complicates the global push for EVs. A holistic economic model that considers the total cost of ownership, including environmental impacts, health benefits, and grid enhancement costs, should be developed. This model would provide a more comprehensive understanding for policymakers to devise more effective incentives and regulatory frameworks. Harmonizing EV policies internationally could reduce barriers to technology transfer and market penetration.

Understanding the dynamics of EV adoption provides crucial insights into the future of electric mobility. Building on this foundation, the next section explores strategies for optimizing EV integration into power systems and discusses future trends that could shape the trajectory of EV technology and its role in global energy systems.

V. OPTIMIZATION and FUTURE TRENDS

This section examines different optimization strategies that concentrate on the planning of EV operations and their incorporation into the electric grid. The publications that were surveyed were categorized into five main groups based on the optimization aims. Table V contains an overview of the optimization efforts that were surveyed. More specific information can be found in the subsections that follow.

A. ENERGY COST

The literature landscape frequently addressed the significant and recurring topic of the operation and energy cost borne by the grid. Cortés and Martínez created a framework for modeling an electric grid as an undirected graph with a tree topology. In this framework, EVs are represented as branches (edges) of the graph [119]. The problem is defined with a population of EVs of size N. The goal is to reduce the overall energy cost during a specific planning period, while considering the limitations on power capacity, by utilizing a penalty function. Unfortunately, the model does not accurately represent the non-linear characteristics of the battery. The authors made another attempt to address scheduling restrictions and introduced a price leveling mechanism for EV charging [120]. The goal was to minimize energy consumption of both EV and non-EV loads to reduce overall energy cost, while also improving grid stability.

Lopéz and Cordero-Moreno introduced a mixed integer programming model for coordinating the charging of EVs. The approach aims to reduce the cost of operation by determining the most efficient charging plan for EV batteries, resulting in the lowest energy expenses [121]. The effectiveness of the suggested model was verified on a system consisting of 136 nodes, with priority given to the validation process.

In a comprehensive study, an optimization model was suggested to account for the expenses associated with energy production and distribution to EVs, the costs incurred from delayed customer satisfaction due to postponed demand, and the revenue produced from services provided to EVs. The analysis was conducted on an actual scenario to determine the most efficient schedule by taking into account the possibilities for combining a photovoltaic (PV) plant, which generates renewable energy, with energy storage facilities. The suggested formulation represents the behavior of multiple stakeholders, such as EV owners, system operators, charging stations, and production plants [122].

To delve deeper into the aspect of scheduling charging in V2G integration, a multi-objective optimization problem was proposed. This problem utilizes linear programming to optimize the timing of charging and discharging, with the goal of reducing the peak to average demand ratio (PAR) and energy cost at charging stations that are connected to smart meters [123]. The implemented decentralized strategy for load scheduling sought to minimize the peak to average (PAR) ratio, reduce the time required for charging and discharging, and optimize energy usage.

TABLE V
SUMMARY OF EXISTING POLICIES TO INCREASE EV ADOPTION

Optimization Focus	Reference	Objective(s)	Optimized Decisions
Energy cost	[119] [120]	Minimize the cost of consumed energy	Charging/discharging scheduling
	[121]	Minimize the total operational costs of the electrical distribution networks	Charging/discharging scheduling
	[122]	Minimize energy production costs, net acquisition costs, and costs of service delay	Charging/discharging scheduling
	[123][124]	Minimize peak to demand average ratio; and overall energy cost	Charging/discharging scheduling
Charging cost	[125]	Minimize charging cost for customers; and minimize gap between instantaneous and average load for valley filling	Charging scheduling
	[126]	Minimize charging cost of EV vehicle at household level	Charging scheduling
	[127]	Minimize investment costs and power losses	Capacity of the charging station and the energy storage system
	[128]	Maximize profit	Location and number of chargers for charging stations
Demand-side management	[129]	Minimize load fluctuation in distribution network	Charging, discharging and power mode switching scheduling
	[130]	Maximize expected profit for multiple stakeholders	Hourly demand allocation and power generation in a grid
	[126][131] [132] [133]	Minimize charging cost of EV vehicle at household level	Charging scheduling
Grid performance	[134] [76]	Minimize the voltage unbalance factor	Charging scheduling
	[135]	Maximize the power system capability	Network reconfiguration and demand response related decisions
	[136]	Minimize charging and discharging costs	Charging/discharging scheduling
	[137] [138]	Minimize the overall variance of total load power	Charging/discharging scheduling
	[139][140] [141]	Minimize total operational costs; maximize the lifetime of the transformer	Charging scheduling
Environmental consideration	[142]	Minimize CO_2 emissions resulting from EV use	Charging scheduling
	[143]	Minimize total CO_2 emission from transportation and power generation sectors	Determining the number of every EV type to operate in the grid and their power generation plan
	[144]	Minimize cost of emission (penalty function)	Scheduling of thermal units integrated with PHEVs

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B. CHARGING COST

Aside from the emphasis on the expenses borne by the grid operator (distribution operator), the charging cost has consistently been the central focus of optimization endeavors in V2G. Multiple investigations were undertaken with the goal of achieving this objective [123]. An effective strategy for reducing the cost of charging EV batteries is to enhance the grid load factor. This technique aims to decrease the charging expenses borne by EV owners through coordinated efforts [125]. This approach involves solving a scheduling problem that takes into account the voluntary price-demand response from customers to shape the load profile. It also considers the limitations of the grid capacity in both scheduled (day-ahead) and real-time scenarios. The problem of pricing structures in a residential area was resolved by employing restricted quadratic optimization, taking into account the perspectives of both EV owners and the utility. This approach resulted in a mutually beneficial outcome for all parties, creating a win-win situation. However, this study did not take into account any random behavior in both demand and sudden price adjustments, which provides an opportunity for future enhancements [126] conducted a thorough examination of algorithms that are currently being used, focusing on both unidirectional and bidirectional methods. Upon conducting tests on seven recognized optimal algorithms, known for their effectiveness, using 1000 examples with varied price structures, a novel method was presented. The objective of this strategy is to minimize the cost of billing with improved efficiency compared to the tested algorithms.

The research examined the optimization of the design of an EV charging station that operates DC bus and a storage system from a design perspective [127]. The goal was to determine the most efficient dimensions for both charging stations and a storage system in order to minimize investment expenses and reduce power losses and stresses on the power grid. The primary results indicated that sizing charging stations according to typical demand, in conjunction with a storage unit, might significantly decrease the power rating compared to sizing it based on peak demand data [128]. Similarly, a method based on optimization was introduced to assist in the development of an EV charging network [129], [145]. The authors initially formulated the problem using a mixed-integer programming approach with the goal of maximizing profit. However, they encountered difficulty in directly solving the problem. In order to overcome the challenges given by the computational complexity, the authors have put forward pre-processing, merging, and eliminating procedures to facilitate the efficient resolution of the problem. Through the utilization of simulation, they confirmed that their suggested algorithm facilitated the attainment of solutions that decreased the quantity of chargers and charging stations, while simultaneously augmenting the profit earned by charging service providers [146] [147].

C. DEMAND-SIDE MANAGEMENT

The V2G concept has also been applied in the context of demand side management (DSM). The study explored various methods of demand-side management (DSM) with a focus on the potential of EVs to achieve the desired benefits of DSM, such as reducing the disparity between peak and valley electricity demand and enhancing system stability [132]. A previous attempt involved the development of an optimization model that relied on demand side management tactics [133]. The model implements load shifting and load flattening in response to hourly prices in a smart grid [131] . It considers EVs, along with other loads and generators, as agents that provide support services to the system. A separate research examined the potential for reducing peak electricity use by utilizing Vehicle-to-Grid technology in Smart Grids at the household level [126]. The authors devised two optimization methods with the goal of enhancing load shaving by decreasing energy consumption during peak hours and simultaneously lowering charging costs. The problem was solved using the Quadprog tool integrated into Matlab. Although this endeavor successfully addressed the two issues individually, it is worthwhile to explore a multi-objective mathematical framework that solutions for both objectives either sequentially or concurrently, while also taking into account the uncertainty in demand instead of relying on deterministic demand that is known in advance.

D. GRID PERFORMANCE

Multiple studies have examined the potential pressures that could be caused by the integration of EVs into the grid, such as phase unbalance and overload [134], [76], [135], as well as the depreciation and aging of grid assets [136]. Therefore, the unorganized integration of V2G technology would require optimizing its effect on the distribution grid. The online coordination of EV charging was optimized using a genetic algorithm, which made smart judgments to decrease the voltage imbalance factor (VUF) [137].

A study was conducted to examine the effect of EV charging on a three-phase distribution grid in a residential neighborhood, taking into account the voltage limitations as outlined in reference [138]. An optimization model, namely a mixed integer non-linear programming model, was employed to maximize the capabilities of the power system when integrating EV charging into an active distribution system.

A study was conducted to evaluate the potential of using a mixed integer linear programming model to achieve frequency regulation and enhance the stability and dependability of the grid [139]. The problem's purpose was to reduce the cost of charging and discharging during various time slots, resulting in benefits for both EV owners and energy providers.

A separate study examined the feasibility of utilizing EVs as a bidirectional energy storage system to mitigate fluctuations in the load profile [140]. This study proposes a mathematical model to efficiently schedule the stochastic operation of V2G systems, taking into account the variable availability of charging resources. The goal was to regulate the variability in the load curve, hence enhancing the dependability and steadiness of the power grid. The literature has addressed the influence of EV charging and discharging on the aging of grid assets, namely the shortening of the lifetime of distribution transformers [141]. A suggested optimization model aims to minimize the loss of life of the distribution transformer while also satisfying the charging demand of EV owners [142]. In this centralized arrangement, the attributes of transformers were taken into account and it was believed that customers would adjust their charging benefits accordingly. Further analysis is required to determine whether customers will participate in the suggested method, especially in the absence of a tariff incentive.

E. ENVIRONMENTAL CONSIDERATION

The transition to EVs aids in the reduction of carbon and other greenhouse gas emissions [148] [143]. A study assessed the impact of increased EV adoption on lowering greenhouse gas (GHG) emissions from the transportation sector in China. Fig. 9 indicates that, in optimal circumstances, replacing an Internal Combustion Engine Vehicle (ICEV) with an EV can result in a decrease of greenhouse gas (GHG) emissions during the use phase alone, ranging from 2% to 43%. A comprehensive life-cycle assessment was performed, which determined that EVs have a lower pollution impact compared to internal combustion engine vehicles (ICEVs) [144]. Therefore, in addition to the previously discussed efforts to optimize their economic advantages and reduce strain on electric grids, there were also studies conducted to examine the environmental impact of EVs, specifically in terms of emissions. A paradigm for optimization was created to assess strategic scheduling patterns that minimize CO_2 emissions [149].

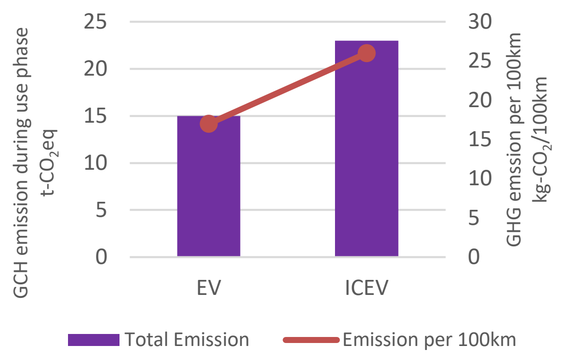

FIGURE 9. GHG emissions for EV and ICEV during use phase

Furthermore, the study conducted by [145] examined the most efficient quantity of EVs for each of the three pre-selected types with varying specifications, with the goal of minimizing the overall carbon dioxide (CO_2) emissions. However, the charging assumptions in this problem were simplified by assuming that automobiles are fully charged once they are at home, thereby eliminating the possibility of needing to charge during any distance traveled. Additionally, it was assumed that EVs always go the same distance. Put simply, the text does not provide any optimal scheduling method for charging or explicitly address the issue of discharging. An efficient scheduling algorithm for charging and discharging EVs has been devised to minimize emissions in a unit commitment problem. The optimization model incorporated emissions as a cost, specifically using a penalty function, and was evaluated over a 24-hour time period. The study showed that the cost of emissions is lower when EVs are connected with the generating units [146].

Optimization strategies and emerging trends offer a glimpse into the potential future of EVs. However, to fully realize this potential, it is essential to address the key insights and challenges identified throughout this study. The following section summarizes these insights, highlighting the remaining obstacles and opportunities for successful EV adoption and integration.

VI. KEY INSIGHTS AND CHALLENGES

The successful integration of EVs into the power grid requires a comprehensive analysis of both technical and social variables. This analysis is necessary to evaluate the possible benefits and drawbacks, as well as to identify the obstacles, possibilities, and gaps associated with EV integration.

Regarding charging technology, it is crucial to establish a uniform standard for charging infrastructure and components. This would ensure widespread acceptance across countries and reduce manufacturing costs through standardization. The compatibility issues between EV models and charging stations continue to challenge convenience, as not all charging stations can deliver the required charging levels for all EV models.

At a strategic level, research is ongoing to design an appropriate framework for integrating EVs into the power grid. In this framework, EVs are seen as both a regular load, a storage source, and a communication node within an integrated network. Therefore, progress in smart grid technology will mainly propel the growth of EVs that can be connected to the grid. The importance of the aggregator agent cannot be overstated in anticipation of the increased use of EVs and their integration into the power grid.

The literature clearly demonstrates that many research have examined both the adverse effects of integrating EVs into the grid and their ability to provide auxiliary services. However, it is clear that varying concentrations of EV loads introduce considerable uncertainty in both time and space, which is further complicated by the inherent complexity of load forecasting.

Another aim of the literature study was to gain a deeper understanding and conceptualization of the many obstacles and motivators for EV adoption. This information can then be used to develop strategies and policy tools to encourage a greater uptake of EVs. In order for EV to have a significant presence in the market at a national level, stakeholders must collaborate to improve visibility, awareness, and market acceptance. Crucially, offering solutions that are attractive to the many demographic groupings. The literature indicates that the hurdles and drivers of EV adoption are intricate and multifaceted, and cannot be effectively addressed in isolation due to their interconnected nature. Instead, a whole ecological approach is necessary.

To enhance customers' impression of EVs and boost their inclination to acquire them, it is necessary to initiate awareness efforts highlighting the financial incentives and advantages of EVs. These campaigns should aim to rectify any misconceptions regarding the perceived inferiority of EVs. Increasing awareness will ultimately inform customers' purchasing decisions as knowledge of incentives, once established, can stimulate consumer interest. Therefore, marketing strategies should be formulated to prioritize the ways in which EVs can enhance consumer convenience and provide environmental advantages.

Due to the unique challenges faced by the EV market, it is crucial to develop government-led strategies that stimulate consumer demand. These strategies should include subsidies for EV registration, incentives for vehicle purchases, and subsidies for home chargers. Additionally, implementing convenient measures like free parking policies, which have proven effective in boosting EV sales in other countries [106], would be beneficial. It is crucial to highlight that the government must ensure the flexibility and adaptability of policy instruments to effectively cater to the unique characteristics of its community, including both residents and citizens. An impending challenge is the restricted range of EV models available. Existing research indicates that the expense associated with owning an EV is a significant obstacle to its widespread adoption. This is because the currently available EV technologies have a high buying price. Many potential users/owners are unwilling to invest in a car with significant fixed costs unless there are other economic incentives. One commonly used method to encourage such actions among consumers is to decrease taxation. While it may not be immediately feasible in nations that have tax exemptions for non-business transactions, it is worth exploring as a potential avenue to promote the adoption of EVs at the individual level.

Successful implementation of electric mass transit buses, coupled with a rise in ridership, has the potential to enhance the appeal of EVs as a mobility choice for individuals. Increased adoption of public electric buses can lead to a significant reduction in the average distance traveled each trip by personal vehicles, as individuals may be limited to utilizing their cars for shorter first- and last-mile journeys. Consequently, this leads to decreased CO_2 emissions and may also incentivize more people to switch from combustion-based vehicles to EVs due to their convenience for short trips and lower operating costs. Evaluating this situation inside a simulated setting could additionally aid in formulating more effective incentives to increase ridership. Another crucial aspect to take into account when formulating transitioning strategies for EV adoption is implementing a viable and environmentally-friendly business model that encourages the widespread use of EVs. A comprehensive business model should consider both primary stakeholders, such as end-users and operators, as well as secondary stakeholders, such as suppliers and other environmentally conscious businesses that could benefit from EV adoption. The literature analysis found that allowing private investment in charging infrastructure through public-private partnerships (PPP) could increase the acceptance and adoption of EVs. According to a case study focused on Shenzhen, the city's present business model, which combines company innovation with government regulations and regulation, might be improved by encouraging private investment in charging infrastructure under a Public-Private Partnership (PPP) framework [117]. It is important to note that the literature does not provide clear recommendations on how to construct partnership and business models [90]. However, a few studies have examined methods for evaluating these models in various markets (see, for example, [147]).

This paper further examines and evaluates the current body of literature on optimization endeavors in the context of incorporating EVs into smart grids. Although extensive research has been carried out in several fields of study with the goal of optimizing distinct objectives in recent years, there is a noticeable lack of systematic examination in certain areas. Furthermore, the areas that have been studied already show potential for further exploration and improvement. One shortcoming that has been identified is the failure to take into account the stochastic nature of EV demand and availability for charging and discharging. While only a limited number of research endeavors have taken this element into account within their problem settings, it nevertheless merits additional inquiry. Another intriguing topic that arises from the field of operations research is the location and allocation problem, also known as facility planning. This problem aims to optimize the placement and assignment of charging stations in a well-informed infrastructure development. Another notable area for potential optimization is in enhancing public policy to encourage the widespread adoption of EVs and creating favorable market circumstances through the implementation of incentives and levies. Within the framework of demand side management, it is important to conduct additional study on the social behavior, attitude towards pricing, and trust in EVs as they are significant factors to consider. Insufficient research has been conducted on the optimization of electric car battery degradation. It is worth noting that most of the surveyed work focused on optimizing a single objective, rather than addressing the complex problem of vehicle integration. This problem involves multiple conflicting aspects and stakeholders, and any solution in this context requires making trade-offs. Therefore, further investigation into multi-objective optimization is necessary. The expected decrease in CO_2 emissions resulting from the incorporation of EVs into the power grid was seldom a goal in the analyzed issues. There is still much work to be done to improve the environmental benefits of V2G and EV technology.

Having explored the insights and challenges associated with EV adoption and integration, we now turn to the conclusion. This final section encapsulates the findings of this study, offering a comprehensive view of the current state and future prospects of electric mobility.

VII. CONCLUSION

This paper provided a comprehensive examination of the current EV charging processes, charging modes, and standards from a technical standpoint. Continued progress in smart grids and EV technologies is crucial to ensure the successful integration of EVs with the power system. It is necessary to evaluate the benefits and advantages. Furthermore, it is crucial to evaluate and measure the adverse effects in a setting that facilitates intelligent charging, dependable communication, and a well-organized framework that takes into account the interests of both EV owners and power grids. This study also examined variables, from a sociological standpoint, that could contribute to the expansion of EV adoption. This includes identifying hurdles and drivers that could either impede or stimulate the widespread adoption of EVs. Four primary domains were identified to facilitate the transition to a broader EV adoption. The four key factors are rules and governance, charging infrastructure, economic feasibility, and business models. The literature uncovered many methods and regulations that have the potential to stimulate the growth of EVs in different cities and regions. The common thread throughout all is the significance of context. Ultimately, we explored many strategies to optimize the planning of EV operations and its integration into the electric grid. Several potential avenues were found that would enhance the current body of material.

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