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Global Trends in Electric Vehicle Battery Efficiency and Impact on Sustainable Grid

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ABSTRACT

Over the past decade, transportation electrification has emerged as a pivotal focus of the article. Electric vehicles (EVs) have progressively gained traction in the market, displacing conventional internal combustion engine vehicles. This surge in EV popularity has led to a corresponding increase in the number of charging stations, thereby significantly influencing the power grid (PG). Various charging strategies and grid integration approaches are being devised to mitigate the potential negative impacts of EV charging while optimizing the advantages of integrating EVs with the grid.

This paper provides a comprehensive overview of the current state of the EV market, standards, charging infrastructure, and the PG's response to the impact of EV charging. The article provides a comprehensive assessment of how forthcoming advancements in EV technology, including connected vehicles, autonomous driving, and shared mobility, will intricately influence the integration of EVs with the PG. Ultimately, the article concludes by meticulously analyzing and summarizing both the challenges and recommendations pertinent to the prospective expansion of EV charging infrastructure and grid integration. The proliferation of venture capital investments in nascent start-up ventures specializing in EV and battery technologies has experienced a pronounced surge, reaching an impressive sum of nearly USD 2.1 billion in 2022. This notable increase represents a substantial uptick of 30% compared to the figures recorded in 2021. Furthermore, these investments have been directed towards two key areas: advancements in battery technology and the acquisition of critical minerals. This discernible shift in investment

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trends underscores the growing recognition of the strategic importance and potential profitability associated with innovations in EV and battery technologies. In 2022, global expenditures on EVs surpassed USD 425 billion, marking a substantial 50% increase compared to the previous year, 2021. Remarkably, a mere 10% of these expenditures can be attributed to governmental support, with the bulk stemming from consumer investments.

الاتجاهات العالمية في كفاءة بطاريات السيارات الكهربائية وتأثيرها على الشبكة المستدامة

محمد شمشير، عبدالله غيث .

ملخص: على مدى العقد الماضي، برزت كهربة النقل كمحور أساسي في المقال. حيث اكتسبت السيارات الكهربائية زخماً تدريجياً في السوق، لتحل جزئيا المركبات التقليدية التي تعمل بمحركات الاحتراق الداخلي. وقد أدى هذا الارتفاع في شعبية السيارات الكهربائية إلى زيادة مقابلة في عدد محطات الشحن، مما قد يؤثر بشكل كبير على شبكة القدرة. ويتم تطوير استراتيجيات شحن مختلفة واساليب تكامل مع الشبكة لتخفيف الآثار السلبية المحتملة لشحن السيارات الكهربائية مع تحسين فوائد دمج السيارات الكهربائية مع الشبكة. يقدم هذا المقال نظرة شاملة على الوضع الحالي لسوق السيارات الكهربائية، والمعايير، والبنية التحتية للشحن، واستجابة شبكة القدرة لتأثير شحن السيارات الكهربائية. ويقدم المقال تقييماً شاملاً لكيفية تأثير التطور المستقبلي في تكنولوجيا السيارات الكهربائية، بما في ذلك المركبات المتصلة، والقيادة الذاتية، والتنقل المشترك، على تكامل السيارات الكهربائية مع شبكة القدرة. في النهاية، يستنتج المقال من خلال تحليل دقيق وتلخيص للتحديات والتوصيات ذات الصلة بالتوسع المستقبلي للبنية التحتية لشحن السيارات الكهربائية وتكامل الشبكة. شهدت الاستثمارات الضخمة لرأس المال الاستثماري في الشركات الناشئة المتخصصة في تكنولوجيا السيارات الكهربائية والبطاريات طفرة واضحة، حيث وصل إلى مبلغ مثير للأعجاب يقارب 2.1 مليار دولار أمريكي في عام 2022. تمثل هذه الزيادة ارتفاعاً كبيراً بنسبة30% مقارنة بالأرقام المسجلة في عام 2021. علاوة على ذلك، تم توجيه هذه الاستثمارات نحو مجالين رئيسيين: التقدم في تكنولوجيا البطاريات واكتساب المعادن الأساسية. يشير هذا التحول الواضح في اتجاهات الاستثمار إلى الاعتراف المتزايد بالأهمية الاستراتيجية والإمكانية الربحية المرتبطة بالابتكارات في تكنولوجيا السيارات الكهربائية والبطاريات. في عام 2022، تجاوزت النفقات العالمية على السيارات الكهربائية 425 مليار دولار أمريكي، مسجلة زيادة كبيرة بنسبة 50% مقارنة بالعام السابق،2021 . ومن الجدير بالذكر أن 10% فقط من هذه النفقات يمكن نسبتها إلى الدعم الحكومي، بينما جاء الجزء الأكبر من استثمارات المستهلكين.

الكلمات المفتاحية – السيارات الكهربائية، البطاريات، البنية التحتية القابلة للشحن، شبكة الطاقة.

1. INTRODUCTION

The electric vehicle (EV) market is projected to maintain robust growth throughout 2023. During the initial quarter, over 2.3 million EV units were sold, indicating a substantial 25% surge compared to the same period in the previous year. Projections anticipate a noteworthy 14 million EV sales by the close of 2023, reflecting a notable 35% year-on-year surge. This momentum is anticipated to accelerate in the latter half of the current year [1,2]. Consequently, electric vehicles are poised to constitute around 18% of the total annual EV sales. Fig. 1 displays the sales of electric cars, 2019 to 2023. Following this, National policies and incentives are poised to play a pivotal role in augmenting sales, while the potential resurgence of elevated oil prices, akin to those observed last year, could serve as an additional incentive for potential buyers [3,4].
In the year 2022, global electric car sales were predominantly influenced by three key markets. China retained its position as the primary market leader, commanding approximately 60% of the total global EV sales. Concurrently, within Europe, electric car sales experienced a notable surge, surpassing a growth rate of 15% over the same period. Consequently, EVs accounted for more than one-fifth of all cars sold within the region [5]. Furthermore, EV sales in the United States

witnessed a remarkable escalation, registering a substantial 55% increase in comparison to the preceding year, thereby achieving a sales share of 8%. Figure 1 illustrates the distribution of EV sales and registrations in World, China, Europe and the US, 2018-22. Figure 2. The distribution of EV sales and registrations in World, China, Europe and the US, 2018-22.

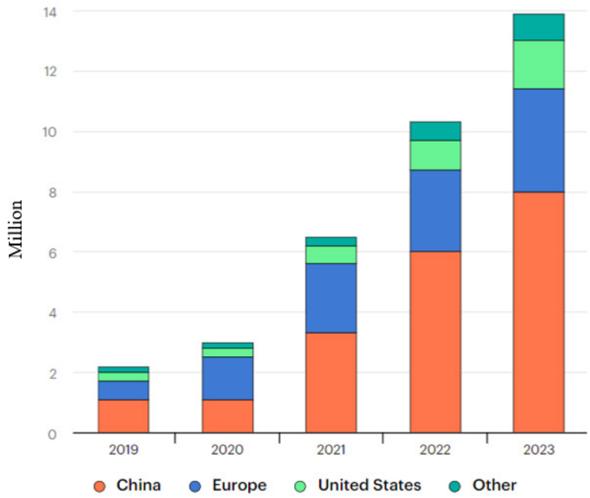

Figure 1. Sales of EV, 2019 to 2023 [5].

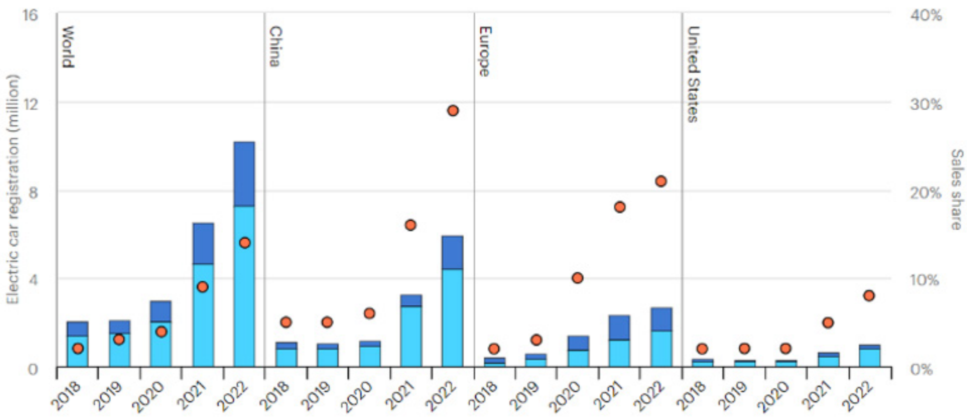

Figure 2. The distribution of EV sales and registrations in World, China, Europe and the US, 2018-22 [5].

In 2022, global expenditures on EVs surpassed USD 425 billion, marking a substantial 50% increase compared to the previous year, 2021. Remarkably, a mere 10% of these expenditures can be attributed to governmental support, with the bulk stemming from consumer investments. Moreover, investor confidence in the EV sector remains resolute, evidenced by the consistently superior performance of EV-associated companies' stocks when juxtaposed with those of traditional automobile manufacturers since 2019 [6-8]. In this regard, Electric vehicles (EVs) are often touted as a more environmentally friendly alternative to their internal combustion counterparts, primarily due to their lower operational emissions. However, the true environmental impact of EVs extends beyond just the tailpipe emissions or lack thereof.

The proliferation of venture capital investments in burgeoning start-up enterprises dedicated to EV and battery technologies has also surged, surmounting nearly USD 2.1 billion in 2022 a substantial 30% rise relative to 2021. Moreover, investments have gravitated towards both battery technology and the acquisition of critical minerals, marking a pivotal shift in investment trends.

The surge in electric vehicle (EV) demand is compelling a corresponding surge in the requisition for batteries and essential associated minerals. The demand for automotive lithium-ion (Li-ion) batteries witnessed a significant uptick of approximately 65%, reaching 550 GWh in 2022 from a baseline of around 330 GWh in 2021. This upswing can be primarily attributed to the burgeoning sales of electric passenger cars. Clearly, in 2022, EV batteries accounted for approximately 60% of lithium demand, 30% of cobalt demand, and 10% of nickel demand. These figures mark a substantial shift from just five years ago when the respective proportions were roughly 15%, 10%, and 2%. In light of recent price fluctuations in battery materials, mitigating the necessity for critical resources assumes paramount importance for maintaining the sustainability, resilience, and security of the supply chain [9,10]. Electric vehicles (EVs) emerged as a solution through the introduction of the vehicle-to-grid (V2G) concept. This concept embodies the utilization of EVs as distributed resources for load management and as devices for generation and storage, all facilitated by their seamless integration into the grid [11]. Although still in its conceptual phase, this approach holds significant promise [12].

While EVs are parked, particularly during periods when they are not actively used for commuting, research has demonstrated that these vehicles, when aggregated, can provide a multitude of valuable services to the power grid. This capability transforms EVs into auxiliary storage units within residential distribution systems [13]. They contribute to both upward and downward regulation, thereby assisting grid operators in maintaining a harmonious balance between supply and demand [14]. Additionally, EVs aid in reducing peak loads and filling demand valleys [15,16], while also fulfilling essential roles in frequency regulation services.

Several studies have explored the effects of EVs on the power grid (PG). According to [17], The study offers a thorough and encompassing exploration of EV behavior modeling and its role in the development of algorithms for integrating EVs with the grid. A range of models has been devised to capture the intricacies of EV usage patterns, the decision-making processes regarding charging, and the manner in which EVs respond to intelligent charging strategies [18,19]. Furthermore, it elucidates the various sub-models that pertain to charging preferences and the nuanced responses of EVs to advanced charging methodologies. In [20] a stochastic bottom-up model aimed at evaluating the influence of EVs on load profiles across various parking sites and their viability for load management tactics. The principle of this approach lies in its incorporation of socio-economic, technical, and spatial variables, all of which exert an impact on the electricity demand and charging behavior within diverse locations. Through meticulous statistical scrutiny of an extensive dataset concerning mobility patterns, the study effectively identifies the most statistically significant factors that shape residential charging behavior.

The objective of [21] is to propose a proficient model along with a robust control strategy, aiming to ensure high-quality power output for an AC microgrid (MG) interconnected with the utility grid while incorporating EVs into the system. The MG encompasses two renewable energy sources: a photovoltaic system (PVS) and a wind turbine system (WTS) driven by a permanent magnet synchronous generator (PMSG), all integrated with an EV. These energy sources collectively contribute active and reactive power to both the AC bus and the utility grid. To optimize the efficiency of the photovoltaic modules and enhance overall performance, the study employs a maximum power point tracking (MPPT) approach based on the perturb-and-observe (PO) method. In [22] elucidated the primary consequences associated with the integration of electric vehicles into the power grid. These ramifications encompass an escalation in short-circuit currents, potential deviation of voltage levels beyond standard thresholds, heightened power demands, and an influence on the longevity of equipment. The article employs a case study approach using the 13-bus system. Within this case study, an assessment is conducted concerning the effects on voltage levels, power demands, and active power losses across various

penetration levels and electric vehicle power demand scenarios.
One of the most significant contributions in the context of the discussed trends in batteries is the impressive growth of China's EV market and its impact on both battery demand and the proliferation of charging infrastructure. China's exceptional battery demand growth, exceeding 70%, and the parallel 80% surge in electric car sales in 2022 compared to the previous year underscore its position as a global leader in the EV industry. Furthermore, China's emphasis on building a comprehensive charging infrastructure network has been a game-changer for electric vehicle adoption. The remarkable total of 760,000 fast chargers by the end of 2022, primarily concentrated within targeted provinces, demonstrates a well-executed strategy to address the challenge of limited home charging access.

2. Trends of EV Technology

The narrative of EVs predates the introduction of internal combustion engine (ICE) vehicles. Nonetheless, despite encountering numerous challenges along the way, EVs had only managed to secure a modest share of the automobile market. Contemporary EV technologies are relatively recent, and their appeal is rapidly growing owing to a multitude of benefits, including zero emissions, liberation from fossil fuel dependency, efficiency, minimal noise generation, and more. Research endeavors pertaining to EVs have centered on enhancing their range and efficiency, driving down costs, and innovating efficient charging infrastructure.

2.1. EV Status

Electric vehicles (EVs) can be categorized into two primary groups: hybrid electric vehicles (HEVs) and all-electric vehicles (AEVs). AEVs exclusively employ electric motors that draw power from electrical sources. AEVs can be further divided into two subcategories: Battery EVs (BEVs) and Fuel Cell EVs (FCEVs). Unlike FCEVs, which don't necessitate external charging, BEVs rely entirely on grid-supplied external power for recharging their storage units. Another variant of HEVs is the plug-in hybrid EV (PHEV), which offers the option to recharge its battery from the grid. In this study, the collective term "EVs" encompasses both BEVs and PHEVs [23,24]. Power flow from the energy source to the wheels is explained in Figure 3.
This study by Waseem [25] provided a comprehensive evaluation of the developmental status and challenges associated with various aspects, including the research gap aimed at promoting fuel-cell-based hybrid electric vehicles (HEVs), the primary obstacles encountered in the adoption of fuel-cell-based HEVs, the progression of electric mobility and its powertrain technology, the electrochemical principles underlying fuel cell technology for fuel cell electric vehicles (FCEVs), the various power transformation topologies, communication protocols, and advanced charging methodologies, recommendations and future outlooks concerning fuel-cell HEVs, and prevalent research trends within the domain of electric vehicles (EVs) and FCEVs. The article deliberated on the significant challenges faced by fuel cell electric mobility, encompassing issues such as suboptimal fuel cell performance, challenges related to cold starts, difficulties in hydrogen storage, imperatives for cost reduction, safety considerations, and the optimization of traction systems.
In [26], the article conducted an evaluation of the technological statuses pertaining to various powertrain systems within Battery Electric Vehicle (BEV) technology. It delineated specific technological domains anticipated to undergo significant advancements, with a concentrated focus on reviewing available information and data concerning EV architecture, electrical machinery, optimization methodologies, and the potential avenues for future developments conducive to sustainable mobility.
The challenges associated with the commercialization of diverse electric drivetrain configurations were deliberated upon. The principal aim was to furnish a comprehensive overview of

contemporary pure electric vehicle powertrain technology and envisaged trajectories for the development of environmentally friendly vehicles, thereby offering insights to guide future research endeavors within this sector.

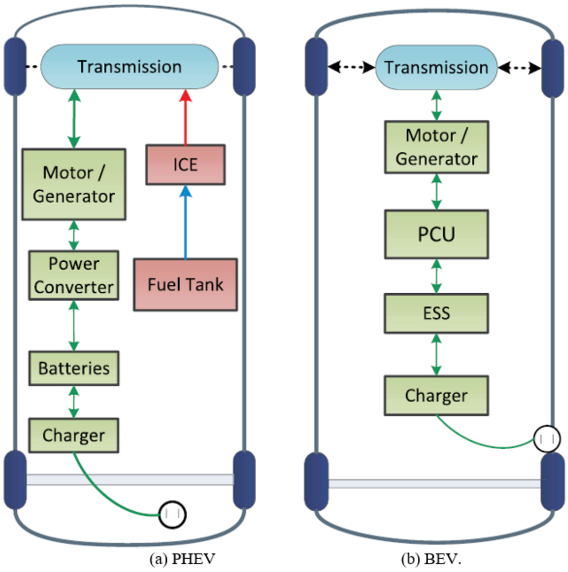

Figure 3. Power flow in several types of EVs (a) PHEV, (b) BEV.

According to [27], the paper offered insights into the motivational factors underpinning consumers' preferences for Electric Vehicles (EVs), under the presumption of both equivalent and disparate pricing scenarios between EVs and conventional vehicles. Drawing upon consumer behavior principles, the analysis elucidated that individuals driven by reputation considerations tend to favor EVs solely when the purchase cost exceeds that of traditional vehicles. Consequently, the findings suggest that genuine environmental conscientiousness may be overshadowed by reputation-driven motives. Furthermore, the paper highlighted that the appeal of EVs as sustainable products is accentuated only under circumstances where prices are relatively elevated. Additionally, the study provided elucidations regarding the impact of sociodemographic variables, automotive attributes, and external environmental factors on consumer preferences within this domain.

2.2. Trends in Batteries

The demand for automotive lithium-ion (Li-ion) batteries witnessed a remarkable surge of approximately 65%, reaching 550 GWh in 2022 compared to about 330 GWh in 2021. This surge can be primarily attributed to the rapid expansion of the electric passenger car market, evident in a remarkable 55% increase in new registrations in 2022 compared to the previous year [5]. It is clear that, China experienced an exceptional battery demand growth for vehicles, exceeding 70%, paralleled by an impressive 80% surge in electric car sales in 2022 relative to 2021. However, this growth in battery demand was somewhat moderated by the increasing presence of Plug-in Hybrid Electric Vehicles (PHEVs). Figure 4. Presents the classification of EVs.
Meanwhile, the United States observed an 80% upswing in battery demand for vehicles, despite electric car sales only growing by about 55% in 2022. Even though the average battery size for battery electric cars in the United States exhibited a modest 7% expansion in 2022, it remains approximately 40% larger than the global average [29]. This phenomenon can be attributed to factors such as the higher prevalence of SUVs in the US electric car market compared to other major markets, as well as manufacturers' strategic emphasis on extending all-electric driving

ranges. It is anticipated that electric cars and vans will maintain their prominence in constituting the predominant portion of total battery demand for EVs, encompassing approximately 90% of the overall demand across both projected scenarios.

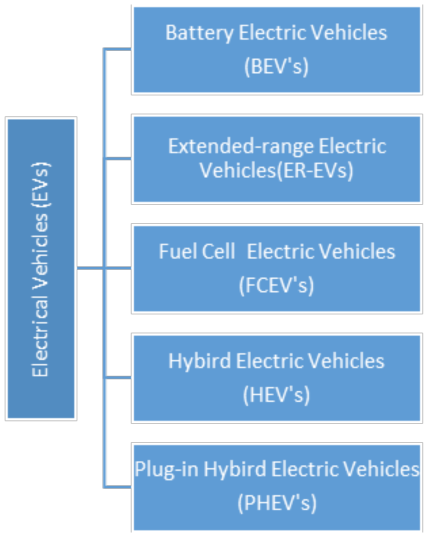

Figure 4. The classification of EVs [28].

Within the Advanced Policy Scenario (APS), the projected battery demand is forecasted to attain 120 gigawatt-hours (GWh) for buses and 160 GWh for two/three-wheelers by the year 2030. Figure 5 displays the estimated battery demand for each mode from 2022 to 2030.

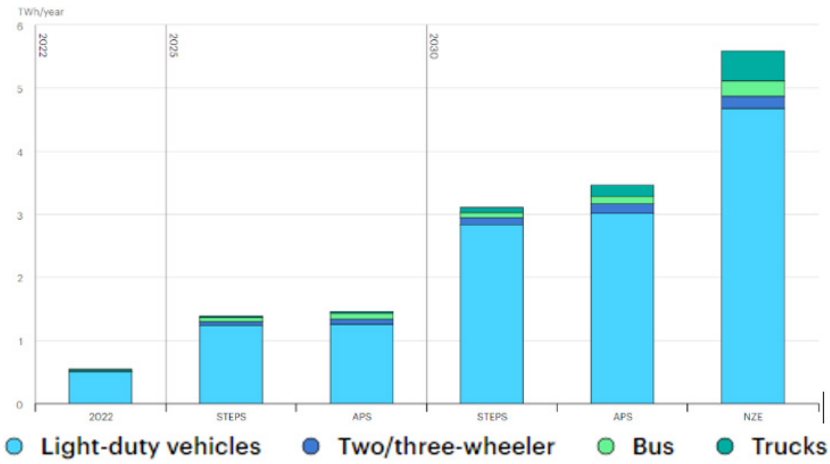

Figure 5. The estimated battery demand for modes, 2022-30.

Following this, the battery demand for trucks exhibits a substantial increase, escalating to approximately 80 GWh in the Stated Policies Scenario (STEPS) and 170 GWh in the Advanced Policy Scenario (APS) by the same time frame of 2030.

However, several scholarly works have delved into the trends pertaining to advancements in trends battery technology. As asserted by Ntombela [30], the paper undertook an investigation into diverse Electric Vehicle (EV) drive circuit architectures, elucidating their configurations and evaluating the associated merits and demerits. Subsequent sections of this article elucidated the contemporary status of battery technology with a primary focus on batteries employed in EVs. Furthermore, an in-depth examination was conducted regarding optimal electric motor selection criteria for EV applications, with considerations encompassing parameters such as efficiency, power density, fault tolerance, dependability, and cost-effectiveness, among others. Additionally, the study delved into an extensive exploration of the challenges and prospective benefits associated with the adoption of EVs in forthcoming periods. While advancements in areas such as charging efficiency and battery performance showcase promising developments, it was underscored that governmental regulation pertaining to EVs represents a significant non-technical impediment that necessitates attention. In the current context of the ban on fossil fuel vehicles (diesel and petrol) adopted by several European cities, the question arises of the development of the infrastructure for the distribution of alternative energies, namely hydrogen (for fuel cell electric vehicles) and electricity (for battery electric vehicles). The article [32] compared the main advantages/constraints of the two alternative propulsion modes for the user. The main advantages of hydrogen vehicles are autonomy and fast recharging. The main advantages of battery-powered vehicles are the lower price and the wide availability of the electricity grid. the article then reviews the existing studies on the deployment of new hydrogen distribution networks and compare the deployment costs of hydrogen and electricity distribution networks. This paper [33] scrutinized the factors exerting influence on the adoption of Battery Electric Vehicles (BEVs) among early adopters. The inadequate comprehension of consumer motivations impairs the formulation of effective policies aimed at fostering adoption. To address this gap, we contributed novel insights pertaining to Ireland by examining the primary determinants of BEV uptake during the initial stages of technology diffusion. This was achieved through the integration of Irish census data and BEV uptake statistics at a finely-grained spatial resolution, marking the first instance of such an approach in the Irish context. In [34], the study encompassed a series of full-scale fire experiments designed to enhance comprehension regarding the thermal dynamics of fires involving Battery Electric Vehicles (BEVs). The investigation focused on elucidating the thermal behaviors associated with BEV fires. To furnish current insights into BEV fires, the study selected the most recent BEV model boasting a substantial electric energy capacity of 64 kWh. For the purpose of comparative analysis, both a lithium-ion batteries (LIB) pack and a BEV body underwent individual testing subsequent to physical disassembly. Additionally, assessments were conducted on an internal combustion engine vehicle and a hydrogen fuel cell electric vehicle. Throughout the experimental trials, combustion within the BEV fires persisted for approximately 70 minutes, facilitating the determination of critical fire characteristics. Measures including the peak heat release rate (pHRR), total heat released (THR), fire growth parameter, and the average effective heat of combustion were quantified, yielding values ranging from 6.51 to 7.25 MW, 8.45 to 9.03 GJ, 0.0085 to 0.020, and 29.8 to 30.5 MJ/kg, respectively.

2.3. Trends in charging infrastructure

Although a significant portion of the current charging demand is effectively addressed through home charging solutions, the escalating requirement for publicly accessible charging stations has become increasingly pronounced. This shift is crucial to ensure that EVs) match the convenience and accessibility standards of conventionally fueled vehicles. This transition is particularly imperative in densely populated urban areas, where limited access to home charging facilities prevails [35]. In such contexts, the establishment of public charging infrastructure plays a pivotal role in expediting the adoption of EVs. As of the conclusion of 2022, the global count of public charging points has reached an impressive 2.7 million, with over 900,000 of these being newly installed within the same year. This surge reflects a notable 55% increase relative to the stock in 2021, aligning closely with the pre-pandemic growth rate observed between 2015 and 2019, which stood at 50%. This evolution underscores the vital role played by public charging networks in accommodating the soaring demand for EVs and sustaining their upward trajectory in popularity. As high-efficiency electric vehicles (EVs) become increasingly prevalent, the infrastructure supporting them must evolve to meet new demands. This introductory analysis emphasizes the urgent need for a systematic exploration of the infrastructural improvements required to accommodate these advanced vehicles. Key areas of focus include the expansion and enhancement of EV charging stations, upgrades to existing grid capacity, and the integration of renewable energy sources.

2.3.1. Slow Charging

On a global scale, over 600,000 public slow charging points were deployed in the year 2022, with a substantial portion of 360,000 being established in China. This influx elevates China's collection of slow chargers to surpass the remarkable 1 million mark, firmly positioning it as the predominant hub for public slow chargers across the globe. As of the conclusion of 2022, more than half of the worldwide inventory of public slow chargers was located within China [36]. Following China's lead, Europe emerges as the second-largest contributor in the realm of public slow-charging infrastructure. In the year 2022, Europe bolstered its total slow charger count to 460,000, signifying an impressive 50% surge compared to the preceding year. The Netherlands spearheads this movement with an admirable 117,000 slow chargers, while France and Germany follow with approximately 74,000 and 64,000 respectively. Conversely, the United States witnessed a more modest 9% expansion in its slow charger inventory in 2022, marking the lowest growth rate among major markets. In Korea, however, the pace of progress has been notably more rapid, doubling the stock of slow chargers on a year-on-year basis to achieve a commendable count of 184,000 charging points [37].

2.3.2. Fast Charging

Publicly accessible rapid chargers, particularly those strategically positioned along highways, play a pivotal role in facilitating extended journeys and effectively mitigating range anxiety, a prevalent concern that has historically hindered the widespread embrace of EVs. Much like their slow-charging counterparts, public fast chargers extend charging solutions to individuals who lack reliable access to private charging infrastructure. This inclusive approach serves to propel EV adoption across a broader spectrum of society.

In the year 2022, the global count of fast chargers witnessed an augmentation of 330,000 units. It's worth noting that a substantial proportion, almost 90%, of this expansion emanated from China. This fast-charging boom holds significance as it effectively addresses the challenge of limited home charging access, particularly in densely populated urban centers. Moreover, this aligns seamlessly with China's ambitious agenda for swift EV proliferation. China, with its remarkable total of 760,000 fast chargers, takes a resounding lead. Intriguingly, over 70% of the entire inventory of public fast chargers is concentrated within merely ten provinces, underscoring the targeted deployment strategy within the nation [38]. Tammi et al. [39] engaged in an extensive discussion concerning contemporary trends in the charging infrastructure planning of charging infrastructure for EVs. The researchers adopted diverse methodological approaches, incorporated various objective functions, and employed a spectrum of optimization algorithms to address the multifaceted challenge of determining optimal charging station placements. The intricate and dynamic nature of this problem has necessitated the exploration and application of an array of optimization algorithms by researchers seeking viable solutions. Within the purview of this review, particular attention is devoted to scrutinizing research endeavors pertinent to the strategic planning of charging infrastructure tailored for EVs.

In [40], the paper predominantly delves into an investigation pertaining to the optimal allocation of rapid charging stations, focusing on the maximization of economic benefits and mitigation of grid impacts. Moreover, the study addresses the challenges encountered in the adoption process.

Conversely, the paper also delineates prospective trajectories within the field, including the procurement of energy derived from renewable sources and the advantages conferred by vehicle-to-grid (V2G) technology, encapsulating these future trends in a concise summary.

As posited by Mastoi et al. [41], the paper conducts a comprehensive analysis of research endeavors and advancements pertaining to charging station infrastructure. Central to this analysis are the challenges encountered in infrastructure development and the concerted efforts aimed at standardizing infrastructure configurations to facilitate future research endeavors. Furthermore, the study investigates the optimal siting of rapid charging stations, predicated upon considerations of economic viability and grid impact mitigation. Moreover, the paper delves into an examination of the obstacles associated with adoption processes. In [42], the article illustrates a discernible surge in interest and engagement within the realm of EV charging infrastructure. Moreover, the literature surveyed in this study is systematically organized into distinct thematic categories, with a particular emphasis on two recurrent topics: EV charging planning and optimization strategies pertinent to EV charging infrastructure. Moreover, this review article incorporates empirical investigations focused on the planning of charging networks tailored for EVs. As a result, this analytical endeavor furnishes insights into the most recent trends and research findings within the domain of EV charging infrastructure planning. As per the findings of Gnann et al. [43], the article discerns that the prospective correlation between the prevalence of Battery Electric Vehicles (BEVs) and the availability of public fast charging points may parallel analogous trends observed in the context of other alternative fuels. Specifically, projections suggest a convergence towards a ratio of approximately one fast charging point per 1000 vehicles, particularly for high-power charging rates of 150 kW. Furthermore, the analysis reveals a nominal margin on electricity prices necessary for cost recovery, ranging between 0.05 to 0.15 €/kWh per charging point. Nevertheless, it is underscored that the requisites of charging infrastructure are contingent upon the anticipated evolution of battery capacities and charging power rates, both of which are poised for escalation in the foreseeable future.

3. EV INTERFACED IN THE PG

Until recent times, there was a minimal interplay between the transportation and electric power sectors.

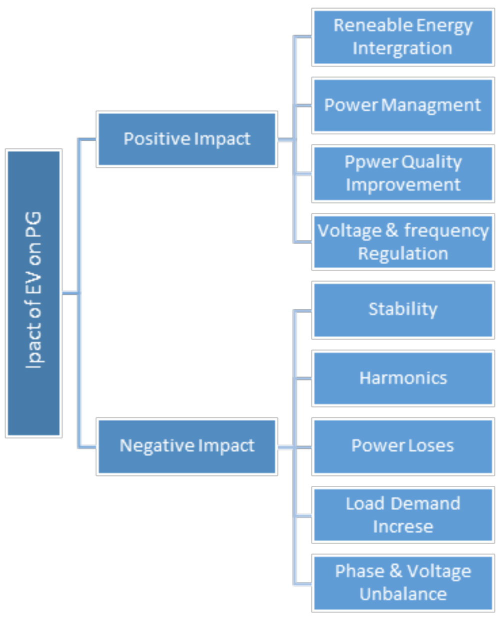

Figure 6. Impact of EV PG-interfaced [47].

The widespread integration of EVs into the transportation landscape has substantially disrupted the conventional business models of electric utility providers [44-46].
As a result, the advent of EVs has introduced a dynamic interplay of significant challenges and considerable benefits to the power grid (PG).
Figure 6, illustrates the impacts of EV PG-interfaced.EVs represent a significant challenge for electric utilities. Excessive integration of EVs into the distribution network can impact the load profile, distribution system component capacity, voltage and frequency imbalances, excessive harmonic injection, power losses, and the stability of the distribution grid as summarized in Table 1.

Table 1. Negative impacts of EV PG-interfaced [48-51].

Impacts	Description
Stability	• EV loads exhibit nonlinearity and demand a substantial power surge within a brief timeframe, thereby inducing instability within the power system.
Phase & voltage unbalance	• The utilization of single-phase EV chargers has the potential to generate phase imbalances, particularly when a significant quantity of EVs is charged concurrently through the same phase.
Harmonics	• EV chargers, being power electronic devices, produce harmonics during the process of power conversion. Consequently, when the penetration of EV chargers is elevated, these harmonics can contribute to harmonic pollution within the PG interface.
Load demand increase	• Unregulated EV charging exacerbates peak-hour loads, posing a substantial challenge for utility companies.
Power Loss	• A substantial integration of EVs into the distribution grid results in a significant surge in real power consumption, contributing to power losses within the PG.

Although excessive EV penetration in the grid can create issues like power quality degradation, rise in peak load, and power regulation problems, all these issues can be resolved using advanced power management techniques. In Table 2, the positive impacts of EV integration on the PG in a coordinated environment are summarized.

Table 2. Positive impact of EV PG-interfaced [52-57].

Impact	Description
Power quality improvement	• Reactive power injection can be regulated as needed. The harmonics by unregulated Distributed Energy Resources (DERs) can be mitigated. • Voltage imbalances can be rectified by redistributing power flow across phases.
Renewable energy Integration	• The variability inherent in renewable energy sources can be effectively mitigated through the utilization of electric vehicles (EVs) as energy storage systems. • Leveraging EVs as buffers for renewable energy can lead to emission reductions and cost savings.
Regulation	• Frequency regulation by correcting grid frequency deviation. • Voltage regulation by supplying/absorbing reactive power.
Power management	• By using scheduled charging/discharging, better power management can be achieved. • Peak load demand can be met by scheduling discharging during peak hours.

4. FUTURE DEVELOPMENT TRENDS OF EV PG INTERFACED

Emerging trends in the future development of EV PG interfaced, beyond their role as mere transportation vehicles, EVs are poised to revolutionize various aspects of the energy landscape.

They can serve as electrical loads, enabling bi-directional power flow from the grid, act as distributed energy storage systems that contribute surplus energy back to the grid, function as energy reservoirs for other EVs, provide energy storage for buildings V2B, and even operate as network communication nodes. These multifaceted capabilities are expected to be further enhanced with the introduction of innovative technologies within the automotive industry, promising to amplify the usability and efficacy of EVs within the context of the modern PG. Cutting-Edge Technologies Shaping the Future of the Transportation Sector Innovation within the realm of transportation is rapidly advancing through a convergence of groundbreaking technologies. These include dynamic wireless power transfer (WPT), connected mobility (CM), the rise of autonomous or self-driving EVs, the emergence of the EV shared economy, and the integration with the burgeoning energy internet. These technological frontiers are poised to reshape the landscape of the transportation sector, ushering in a transformative era. Furthermore, the integration of these technologies into the electrified transportation landscape establishes a close nexus with the power grid, exerting a significant influence on the dynamics of power and energy networks. As these technological innovations unfold within the automotive industry, they inherently chart a path toward the evolution of both transportation and energy domains. To sum up, the integration of advanced battery technologies into the energy grid represents a transformative shift in how energy is stored and utilized, heralding significant implications for grid management and sustainability. As we look to the next two decades, it is imperative that scholarly research focuses on projecting how current and forthcoming advancements in battery technology will affect electrical grid demand. This paper proposes a comprehensive approach that employs predictive modeling to forecast the impact of these technologies. By analyzing trends in battery efficiency, capacity, and integration capabilities, this research aims to provide policymakers and grid operators with a robust and actionable forecast. The ultimate goal is to facilitate strategic planning and efficient resource allocation, ensuring that the grid not only meets growing demand but also adapts to the increasing incorporation of renewable energy sources facilitated by enhanced battery solutions.

5. CONCLUSION

The electric vehicle (EV) market is forecasted to sustain considerable expansion throughout the duration of 2023. In the inaugural quarter, the sale of EV units surpassed 2.3 million, demonstrating a significant increase of 25% in comparison to the corresponding period in the preceding year. Projections envisage a substantial growth trajectory, with an estimated 14 million EV units anticipated to be sold by the conclusion of 2023, reflecting a noteworthy year-on-year surge of 35%. In this article, charging infrastructure, and grid integration facilities continue to advance, there is a projected substantial surge in the adoption of EVs over the coming decade. Consequently, it becomes imperative to foster additional technological breakthroughs. These encompass the development of well-suited smart charging infrastructures, the establishment of dependable communication systems, and the implementation of coordinated charging systems capable of precisely assessing the ramifications on the power grid. These measures are indispensable to fully harness the potential advantages offered by EVs alongside distributed generators. This article comprehensively examines various dimensions of EV charging and grid integration infrastructure. Establishing consistent standards for EVs and their associated charging infrastructure on a global scale is an essential prerequisite for enhancing the market acceptance of EVs. The prominent standards concerning EV charging and PG interfaced are extensively elaborated upon to offer future researchers a comprehensive insight into the requisite specifications.

As electric vehicles (EVs) continue to evolve, a critical aspect influencing consumer adoption rates is the total cost of ownership, which encompasses not only the initial purchase price but also ongoing maintenance costs and energy expenditures. This paper advocates for a detailed economic analysis to explore how advancements in battery efficiency could reshape these financial factors. By improving battery technology, manufacturers not only enhance the performance and range of EVs but potentially reduce costs related to battery production, maintenance, and energy consumption. This analysis aims to provide a comprehensive overview of how these technological improvements could lower the overall ownership costs of EVs.

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