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Review

Comprehensive Review Based on the Impact of Integrating Electric Vehicle and Renewable Energy Sources to the Grid

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Abstract: Global warming, pollution, and the depletion of fossil fuels have compelled human beings to explore alternate sources of energy and cleaner modes of transport. In recent years, renewable energy sources (RES) have been massively introduced to the grid. Furthermore, Electric Vehicles (EVs) are becoming popular as a cleaner mode of transport. However, the introduction of RESs and EVs to the grid has imposed additional challenges on the grid operators because of their random nature. This review aims to focus on the integration of RES and EVs to the grid, thereby presenting the global status of RESs and EVs, the impact of integrating RESs and EVs to the grid, the challenges of integrating RES and EV to the grid, optimization techniques for EV and RES integration to the grid, and mitigation techniques. A total of 153 research papers are meticulously reviewed, and the findings are put forward in this review. Thus, this review will put forward the latest developments in the area of EV and RES integration into the grid and will enlighten the researchers with the unsolved questions in the area that need investigation.

Keywords: electric vehicle; optimization; renewable energy source; power grid; soft computing

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1. Introduction

Globally, pollution, fossil fuel depletion, and greenhouse gas emissions are the most alarming concerns. A paradigm shift from conventional energy sources to renewable energy sources (RESs) is observed. RESs are clean energy sources that emit no greenhouse gases and do not cause pollution. These RESs diversify the energy supply and decrease the dependence on imported fuels. Further, RESs provide avenues for jobs in manufacturing and installation, thereby enhancing economic development. Cheap electricity from RES could provide 65 percent of the world's total electricity supply by 2030. It could decarbonize 90 percent of the power sector by 2050, massively cutting carbon emissions and helping to mitigate climate change [1]. Similarly, EVs are becoming popular as a cleaner mode of transport. EVs are typically powered by a lithium-ion battery that is charged by electricity [2–5]. It is found that, with electricity generation, the carbon emissions of an electric car are around 17–30% lower than driving a petrol or diesel car [6]. However, integrating RESs and EVs into the network results in additional challenges for the grid operators. Some of the challenges associated with RESs are frequency and voltage anomalies, demand and supply mismatches, overloading of existing transmission lines [7–9]. This also includes some of the challenges associated with EV integration are peak load increases, voltage instability, degradation of reliability indices, and harmonic distortions [10–12]. This review aims to focus on the integration of RES and EVs to the grid, thereby presenting the global status of RESs and EVs, impact of integrating RESs and EVs to the grid, challenges of integrating RES and EV to the grid and the mitigation techniques, soft computing applications for EV and RES. Thus, this review will put forward the latest developments in the area of EV and

RES integration to the grid and will enlighten the researchers with the unsolved questions in the area that are worth investigating.

The remainder of the paper is organized as follows. Section 2 presents the existing reviews, highlights the contributions of the work, and elaborates on the search criteria. Section 3 presents the global statistics and research on RES and EV. Sections 4 and 5 present an overview of EV and RES integration into the grid, respectively. Section 6 presents the modeling and decision-making approaches in the case of EV and RES. Sections 7 and 8 present the research on the impact of integrating EV and RES to the grid, respectively. Sections 9 and 10 present the challenges of integrating EV and RES into the grid, respectively. Section 11 presents the optimization techniques applied for EV and RES integration into the grid. Section 12 discusses the key insights of the review. Finally, Section 13 concludes the work.

2. Existing Reviews, Contribution, and Search Criteria

2.1. Existing Reviews

The existing reviews on different aspects of EV and RES are listed in this section, as shown in Table 1. For example, in ref. [13], authors have meticulously reviewed 239 Q1 journals on the topic of EV adoption and put forward the factors affecting the global EV adoption rate. In ref. [14], the status of charging infrastructure development in the UK is reported. In ref. [15], the modeling of solar-based EV chargers is discussed. In ref. [16], data sources for EV-related research are presented. In ref. [17], the importance of smart charging strategies to tackle the increased load demand due to charging is reported. In ref. [18], the research works dealing with the interaction of EVs in a smart grid environment is reported. In ref. [19], the globally prevalent standards for EV charging are reported. In [20], EV-integrated Virtual Power Plants (VPPs) are reviewed in the context of benefits and applicability. In ref. [21], the applications of machine learning for solving the charging infrastructure planning problem are reviewed. In ref. [22], charger placement models are reviewed and compared. In ref. [23], charger placement in the context of smart cities is discussed. In ref. [24], technical and architectural requirements for RES integration to the grid is reviewed. In ref. [25], how RES can enhance the flexibility of power systems is discussed. In ref. [26], the concept and challenges of solar power integration into the grid are critically reviewed. In ref. [27], policies on RES integration into the grid are reviewed. In ref. [28], the effects and associated costs of integrating variable renewables into power grids are comprehensively reviewed. In ref. [29], the power quality challenges imposed by grid-integrated RES are discussed. In ref. [30], authors have reviewed RES integration impacts within the context of generator type, penetration level, and grid characteristics. Furthermore, in ref. [31], optimization techniques for integrating RES with the grid are reported. In ref. [32], the challenges of integrating wind energy into the grid are presented. In ref. [33], the necessity of stationary energy storage for RES integration into the grid is discussed. In ref. [34], applications of blockchain technologies for RES integration into the grid are discussed. In [35], authors surveyed load frequency control considering RES integration with the grid. In ref. [36], the pathways for RES-based electricity generation and supply are discussed.

Table 1. Existing Reviews on EV and RES.

Reference	Year	Topic	Diligence
[13]	2020	EV	Systematic presentation of 239 articles published in various Scopus Q1 journals related to EV adoption
[14]	2020	EV	Comprehensive review of charging infrastructure development in the UK
[15]	2020	EV	Review of PV based EV modelling approaches
[16]	2021	EV	Review of existing data sources for EV research
[17]	2022	EV	Review of smart charging strategies for EVs
[18]	2022	EV	Review of impact of EV charging on smart grid
[19]	2022	EV	Review of the standards and best practices for EV charging
[20]	2022	EV	Systematic review of EV integrated Virtual Power Plants

Table 1. *Cont.*

Reference	Year	Topic	Diligence
[21]	2021	EV	Comprehensive review of machine learning applications for EV charging infrastructure planning
[22]	2021	EV	Comprehensive review of EV charging station planning models
[23]	2021	EV	Overview of charger planning models in the context of smart city
[24]	2019	RES	Review of architecture requirements for integrating RES to the grid
[25]	2020	RES	Survey of challenges of RES integration to the power system flexibility
[26]	2019	RES	Overview of solar power integration to the grid
[27]	2019	RES	Survey of research trends and policy implications of RES integration to grid
[28]	2021	RES	A systematic review of the VRE addition to power grids
[29]	2020	RES	Review of power quality challenges and state-of-the-art mitigation techniques of grid integrated RES
[30]	2019	RES	Review of RES integration impacts within the context of generator type, penetration level and grid characteristics
[31]	2020	RES	Review of optimization models for RES integration to the grid
[32]	2020	RES	Comprehensive review of grid integration challenges of wind energy
[33]	2022	RES	Review of stationary energy storage for RES integration to the grid
[34]	2022	RES	Review of applications of blockchain technologies for RES integration to grid
[35]	2022	RES	Survey on load frequency control considering RES integration with the grid
[36]	2022	RES	Review of sustainable RES electricity generation and supply

2.2. Key Contributions

The key contributions of this review as compared with the reviews listed in Table 1 are as follows:

- Review of the impact of EV and RES integration on power grid presented together
- Overview of global status of RES and EV integration
- Overview of optimization techniques for EV and RES integration to grid
- Review of challenges and mitigation strategies of EV and RES integration

2.3. Search Criteria

The search criteria followed for this review are as shown in Figure 1, thereby explaining the databases covered, the keywords used, and the exclusion criteria.

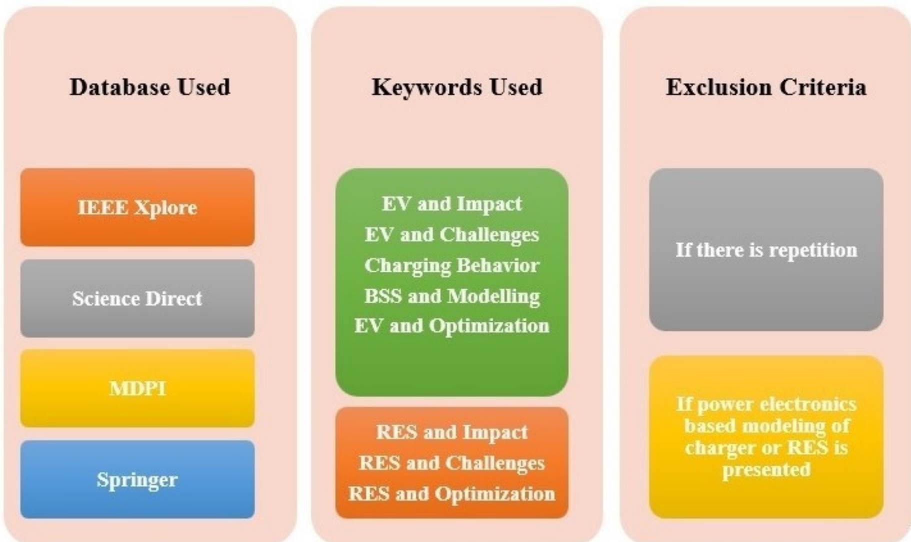

Figure 1. Search Criteria followed in the Review.

3. Global Status of EV and RES

The statistics related to different aspects of EV and RES, as well as the global research on EV and RES, are presented systematically in this section.

3.1. EV Statistics

The global statistics related to EV sales, shares, and chargers are presented in this section. It must be noted that these statistics are collected from global database, such as refs. [37–40].

Figure 2 presents the EV registration and share for the year 2021 for different countries such as Japan, Korea, Canada, United Kingdom, France, and Germany. It is observed that Germany has the highest EV share at 26%. Figure 3 shows the sales of different models of EV for the year 2022. It is observed that the Tesla Model Y was the highest-selling EV for 2022. Figures 4 and 5 show the year wise availability of fast and slow public chargers across different countries, respectively. Figure 6 shows the global distribution of EVs per charging point for the year 2021. It is observed that Norway has the most EVs per charging point.

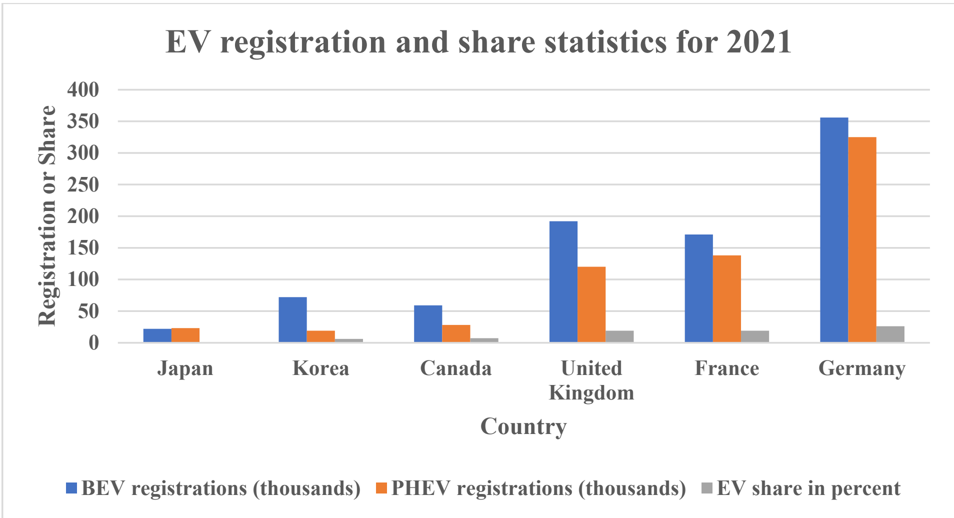

Figure 2. EV registrations and share statistics for 2021 [37].

Figure 3. Sale of different EV models in 2022 [38].

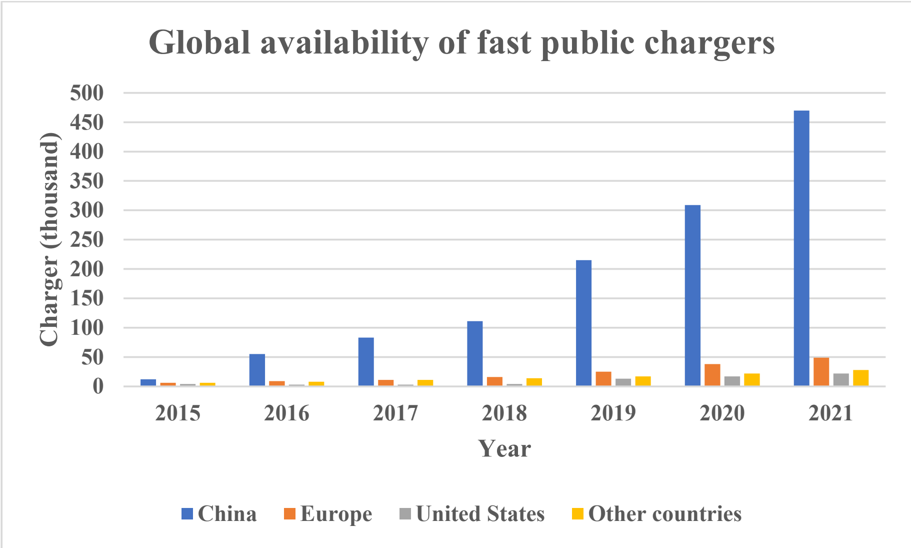

Figure 4. Global availability of fast public chargers [39].

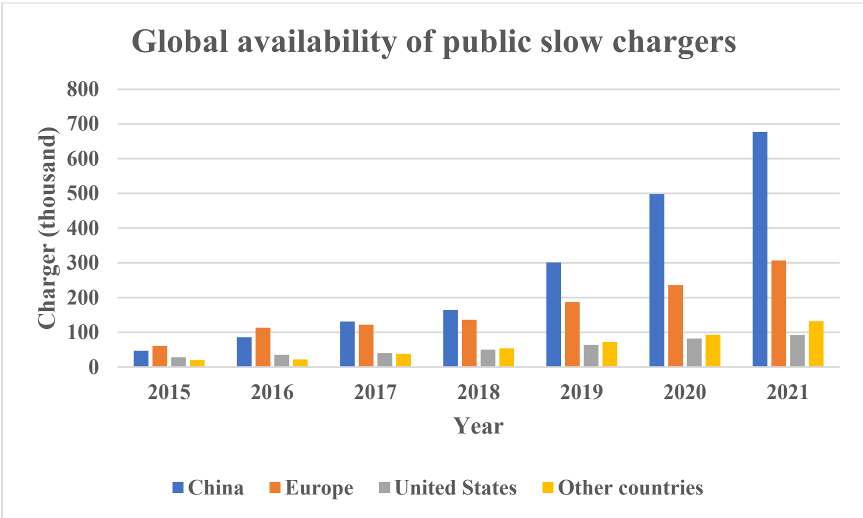

Figure 5. Global availability of slow public chargers [39].

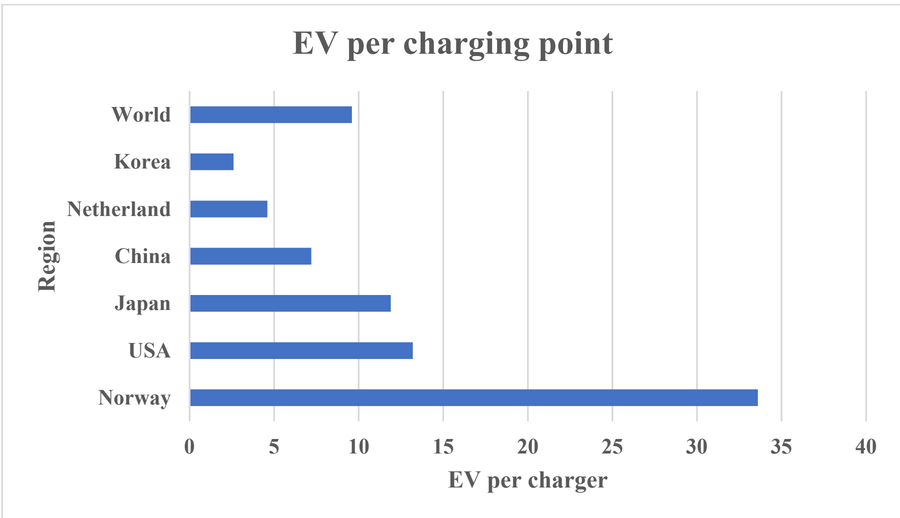

Figure 6. Global distribution of EV per charging point for 2021 [40].

3.2. RES Statistics

The global statistics related to RES generation are reported in this section. It must be noted that these statistics are collected from global databases, such as ref. [41].

Figure 7 shows the variation in renewable energy generation across different countries from 2000 to 2021. It is observed that China has the highest annual change in renewable energy generation at more than 600 TWh. Figure 8 shows the annual change in solar energy generation across different countries. It is observed that China has the highest annual change in solar energy generation at more than 160 TWh. Furthermore, Figure 9 shows the annual change in wind energy generation across different countries. It is observed that China has the highest annual change in wind energy generation at more than 400 TWh.

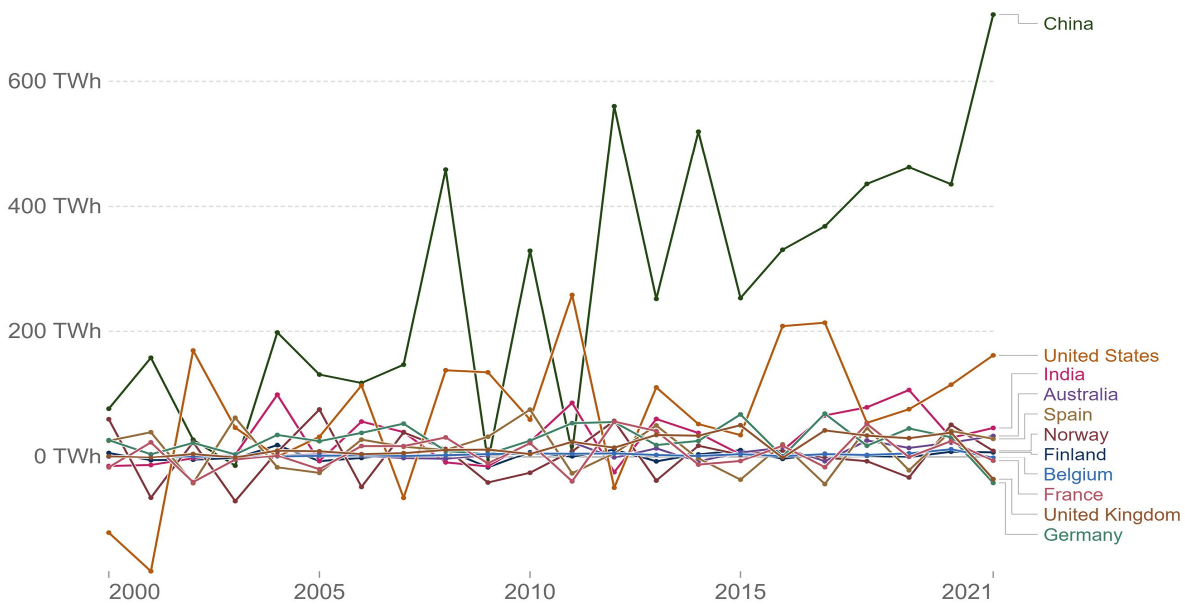

Figure 7. Annual change in renewable energy generation across different country [41].

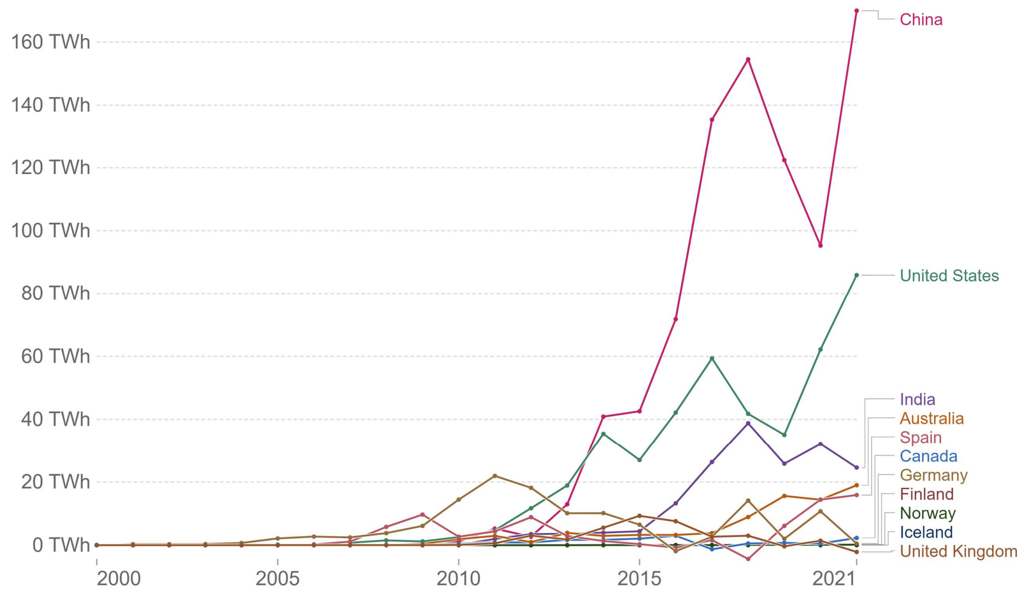

Figure 8. Annual change in solar energy generation across different country [41].

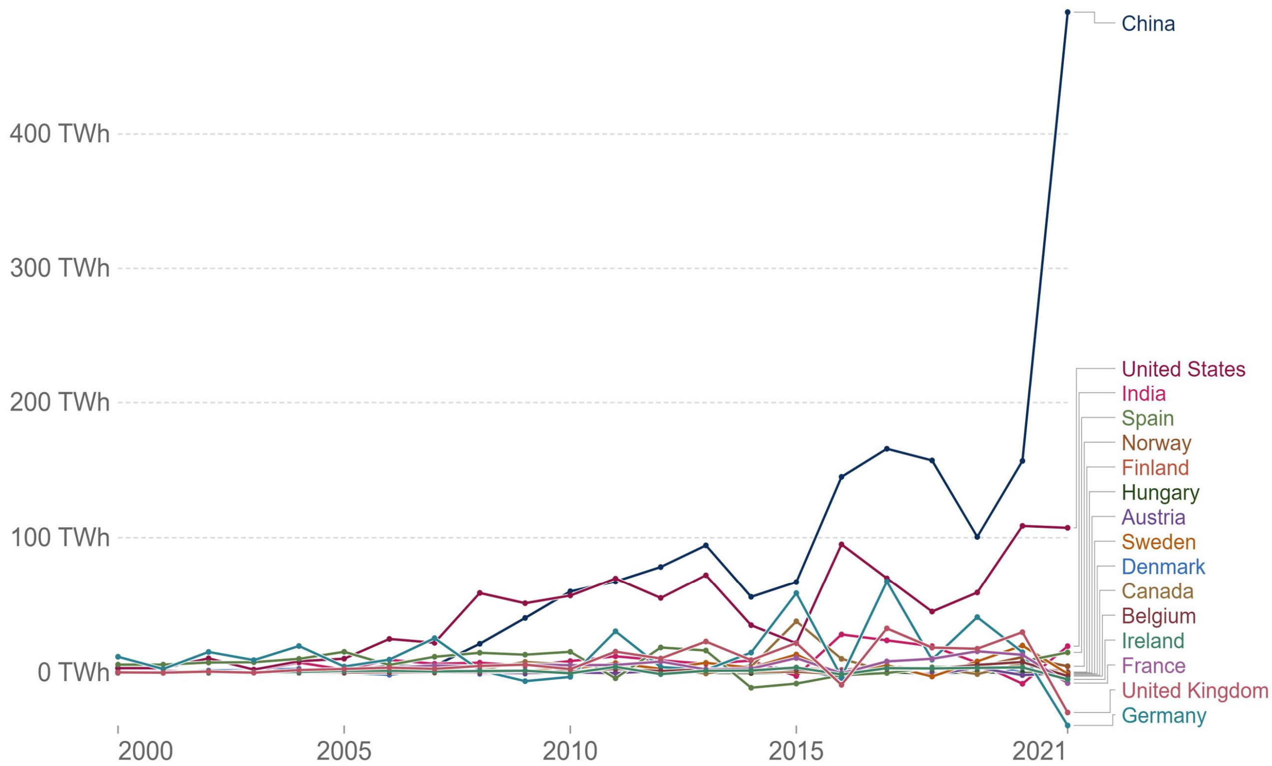

Figure 9. Annual change in wind energy generation across different country [41].

3.3. Global EV Research

The global trends in research on EV and its related aspects are comprehensively reported in this section.

In ref. [42], Kazemzadeh et al. examined the influence of BEVs and PHEVs that can reduce the release of fine particulate matter (PM2.5) with the application of the moment's quantile regression (MM-QR) which has been investigated considering a panel of 29 European nations from 2010 to 2019. The research work examined the association between the rising usage of electric cars and PM2.5 emissions. Their study introduces a new approach, the MM-QR, to examine the correlation between the increasing adoption of electric vehicles and the release of PM2.5. Two models were developed in order to assess their impact on PM2.5 reduction in European nations. The models' nonlinearity was established. The statistical evidence of the parameters was confined to the higher quantiles (75th and 90th), owing to the efficacy of European environmental legislation. Electric cars (BEVs and PHEVs), economic development, and urbanization all help to lower PM2.5 emissions, but fossil fuel usage exacerbates the issue. This study gives insight on how governments and policymakers in Europe may devise plans to increase the usage of electric vehicles.

In [43], Suttakul et al. compared the TCO of EVs to that of traditional ICE vehicles. The authors considered HEV, PHEV, and BEV in the analysis. Cost models were developed considering both capital and operational expenses, including energy consumption, loan interest, the cost of depreciation, upkeep, and taxes. The complete data analysis has been derived from field tests conducted in Thailand. The proposed TCO models were examined utilizing an average urban driving distance of 20,000 km per year for a period of 15 years. ICE, HEV, PHEV, and BEV have a total cost of ownership (TCO) of 61.19, 54.94, 55.55, and 60.89 per $1000 USD, respectively. The research also analyzed the lifetime TCO ratio for each ownership year. It was found that in Thailand, the HEV and PHEV are viable options without BEV support regulations. In addition, the study applies the TCO framework and presents the results as a TCO ratio over a 15-year period, evaluating two hypothetical scenarios where different EV support measures are implemented: either a government subsidy or a discount at the point of purchase, and a reduction in battery prices. The total cost of ownership (TCO) is greatly reduced through direct assistance for the purchase of cars. Government authorities, manufacturer product planners, and consumers might benefit from the information gleaned from this research.

In ref. [44], Nadeem et al., analyzed the CO_2 emission reductions, fuel consumption, and future power demand in Pakistan as a result of the anticipated increase in the number of EVs. The ePop model, which forecasts the future energy consumption of EVs, is used to plan for EVs until 2040. The study evaluates two scenarios: one where 30% of all electric cars and vehicles are in use by 2030, and another where 90% are in use by 2040, both compared with the number of electric vehicles in use in 2020. Consideration is given to PV during the day and the national electric grid at night to meet the anticipated energy consumption. To supply the energy needed for the EVs' consumption of 14.7 TWh/year by 2040, 9 GW of PV capacity will be necessary. On the other hand, 0.7 GW of power plant capacity will be required to fulfill the demand of 4.7 TWh/year. Furthermore, daytime and overnight charging situations for electric vehicles are evaluated. The results predicted a decrease of 10.4 $MtCO_2$ emissions and 9.1 Mtoe of fuel usage in the transportation industry by 2040.

In [45], Wesseh et al. used a game-theoretic method to analyze the interaction between pumped hydro storage, electric vehicles, and climate policy within the electricity market framework. The study focused on the collaboration between the ownership of storage assets and power generation, taking into account various market power dynamics. Chinese electricity market data has been considered to analyze this framework, and it is shown that climate policy may not encourage storage use, especially when companies that hold a dominant position in the storage industry have a limited portfolio of power generation assets. Moreover, when a perfect competitive market is considered, EVs may not increase the welfare of customers in the presence of pumped hydro storage. These findings have a substantial impact on the policy ramifications.

In ref. [46], Li et al. proposed mathematical models for conducting economic analyses of the viability of hydrogen energy generated from RES and then implementing them in the Chinese road transportation industry. The development of a well-to-wheel model to assess the carbon emissions of the hydrogen supply chain and fuel cell EVs. In the interim, a levelized cost of hydrogen model has been formulated to examine the cost of hydrogen as a sustainable energy storage medium. Furthermore, an aggregated cost of ownership model is implemented to estimate the owing cost of and operating a fuel cell EV, powered by hydrogen generated from RES, in comparison to other vehicle powertrains, particularly those powered by fossil fuels. On this basis, the relationship between energy policy and the competitiveness of hydrogen derived from RES and fuel cell EVs is examined.

In ref. [47], Asadi et al. aimed their study at analyzing the elements that influence customers' propensity to utilize EVs. The researchers developed a model based on the Norm Activation Model and the Theory of Planned Behavior to understand the factors that influence people's desire to purchase electric cars. They conducted a survey of potential customers in Malaysia and collected 177 valid responses, using a structural equation model to analyze the data. The results showed that perceived value, attitude, responsibility attribution, subjective norms, personal norms, perceived consumer efficacy, and knowledge of consequences all had a significant and positive impact on customers' willingness to buy EVs.

In ref. [48], Schulz et al. investigated how public charging infrastructure influences the uptake of BEV. Our research has been based on yearly, detailed data on the placement of public charging infrastructure and the ownership rate of battery electric vehicles in 356 Norwegian LAU-2 towns from 2009 to 2019. They concentrated on regions where the initial infrastructure for public charging has been deployed within this time frame. In these mostly rural locations, proliferation began with the installation of the first public charging station. They observed that there has been a rise of 1.5 percentage points, or 200 percent in the local EV ownership rate over five years. In addition, the research outcomes are unaffected by other treatment criteria, such as the median number of public chargers in a region from 2009 to 2019 or the median density of public charging outlets per 1000 residents over the same time period. Although their research cannot rule out the possibility of reverse effects, they identified public charging stations as a stimulant for the spread of BEV.

3.4. Global RES Research

The global trends in research on RES and its allied aspects are comprehensively reported in this section.

In ref. [49], Toklu et al. demonstrated in their research that Turkey has a tremendous potential for renewable energy, particularly hydropower, biomass, geothermal, solar, and wind. The renewable energy technologies of wind, biofuels, solar thermal, and photovoltaics are now maturing and offering the ultimate promise of cost-competitiveness. Environmental pollution is turning into a major worry for the nation as the consumption of energy and power in Turkey increases fast and becomes more reliant on imports of costly fossil fuels that throw a heavy weight on the economy. Concerning worldwide environmental challenges, Turkey's carbon dioxide emissions and energy usage have both increased. States have taken the initiative in safeguarding the environment by lowering the emissions of greenhouse gases. In this sense, RES seems to be one of the most effective and efficient alternatives for Turkey's growth in clean and sustainable energy.

In ref. [50], Poudyal et al. indicate that RES are vital not only for reducing the current energy shortage, but also for achieving energy sovereignty for Nepal through the establishment of dependable and sustainable energy sources. Their research attempted to present an up-to-date view on Nepal's present energy problem, taking into account the dynamic nature of Nepal's energy status and the latest advancements in renewable energy technology. Specifically, the existing profiles of energy production and consumption are analyzed, and the primary reasons leading to the expanding imbalance between energy supply and demand are highlighted. These aspects include deferred and overly expensive hydropower projects, obsolete and inadequate energy infrastructure, transmission and distribution losses, energy theft, inadequate energy governance, a lack of energy sustainability, low equipment effectiveness, inefficient energy pricing models, and inadequate energy market regulations. Specific geographical and geopolitical issues, a large reliance on energy imports, and insufficient use of the huge quantities of renewable energy resources are also significant contributors to the escalation of the energy crisis. The current and future status of significant hydroelectric projects is summarized. Recent policies and investment efforts of the Nepalese government to promote green and sustainable energy are examined. In addition, a long-term prognosis on the energy situation in Nepal is provided using the energy modeling program LEAP to demonstrate how to use Nepal's vast renewable energy resources.

Reference [51], authored by Shakeel et al., proposed that decision-makers and policymakers in Pakistan should have knowledge of energy innovation and resource expansion. They suggested prioritizing certain energy sources and addressing short- and long-term concerns when making decisions. Their research presented a detailed description of the Pakistani power industry and the problems it faces. Moreover, an examination of the country's energy policies throughout the years and their influence on the power industry is provided. The study concluded that Pakistan's current energy profile is not sustainable due to the country's heavy reliance on imported fossil fuels, which leads to increasing electricity generation costs and rising emissions associated with power production. The study presented a clear roadmap and suggested energy sources that may both meet the nation's expanding energy demands and be environmentally responsible. The strategic planning outlined and emphasized the most important steps the nation must take to realize its aim of fulfilling its energy demands and incorporating RES into its power production.

In ref. [52], Ślusarczyk et al. examined the reciprocal relationships between RES and economic development for two European Union countries, as well as the impact on their variations (increase and decrease). A quantitative examination of outcomes was conducted for the economies of low-income Poland and high-income Sweden. This study employed a regression model to examine the existence of relationships between RES, gross incremental energy usage, and economic development. Their research examines data from 1991 until 2022. The findings demonstrated a favorable connection (statistically significant) between the Gross Domestic Product and Gross National Income factors that impact the usage of RES in Sweden (84.6% and 83.7%, respectively) and Poland (79.9% and 79.9%, respectively). The data also indicated that the usage of RES has resulted in a better economic growth rate in the leading nations, but the danger of recession is significantly higher than in other nations. These results would aid state officials and policymakers in comprehending the importance of RES in the economic development of these nations.

In ref. [53], Amhed et al. found that in the future, renewable energy solutions with the lowest operating and externality costs will be the best option. From a policy standpoint, the Pakistani government should support RES and technical development, which requires biomass resources to be connected to non-renewable, protracted expenditures. However, officials have defined several programs to meet energy demand, but they are still unable to close the supply-demand imbalance. 11% of the global population has no access to alternative energy supply and access methods. Moreover, unique strategies for the development of renewable energy have emerged at various times. It covers homes in particular in remote locations without access to gas or electricity. Nonetheless, the aim of this study is to determine the most significant renewable energy source for Pakistan's economy, considering economic benefits such as job creation in the energy sector. This research tries to discover methods for securing energy supplies and generating economic advantages.

In ref. [54], Pereira et al. demonstrated the prospects for the incorporation of new RES into Brazil's energy mix, therefore allowing the country to continue producing a greater proportion of clean energy than the global average. Within the 2010–2030 timeframe, several evolution models for such sources in Brazil and the rest of the globe were evaluated. The analysis revealed not only the advantages offered by any of these sources in the form of GHG emission minimization but also the effect in terms of job creation and the public expenditure required to get these benefits.

4. Overview of EV Integration to Grid

Electrification of transport is one of the key initiatives towards achieving the decarbonization goals. EVs need to be integrated into the grid during charging, and further, EVs can serve as a source by discharging or giving power back to the grid during peak load periods. Different aspects of intergrating EVs into the grid, such as EV behavior modeling and the siting as well as sizing of BSS, are discussed in this section.

4.1. EV Behavior Modelling and Applications

Modeling of EV usage behaviors primarily concerns traveling, parking, and charging activities. Modeling of EV charging behavior is essential for predicting the charging demand and scheduling the charging activities without compromising with the secure operation of power grid [55–60]. The demand for charging an EV depends on trip number, trip distance, energy consumption, and the availability of charging infrastructure. The availability of charging infrastructure is further characterized by parking location, permitted charging power, and intended parking time. EV charging behaviors can be identified from charging profiles or travel and parking activities. The different types of EV usage models are shown in Figure 10.

Temporal usage of EVs indicates the start and end times of different EV usage events, including traveling, charging, and parking, based on which the duration and frequency of each event can be obtained. The temporal usage can be further sub divided into a statistical model, a queuing model, and a time Markov chain model.

EV spatial usage refers to the spatial information of EV activities, including trip destinations, charging locations, and other socio-demographic point of interests (POIs). The spatial usage can be determined by origin destination analysis or trip chain analysis.

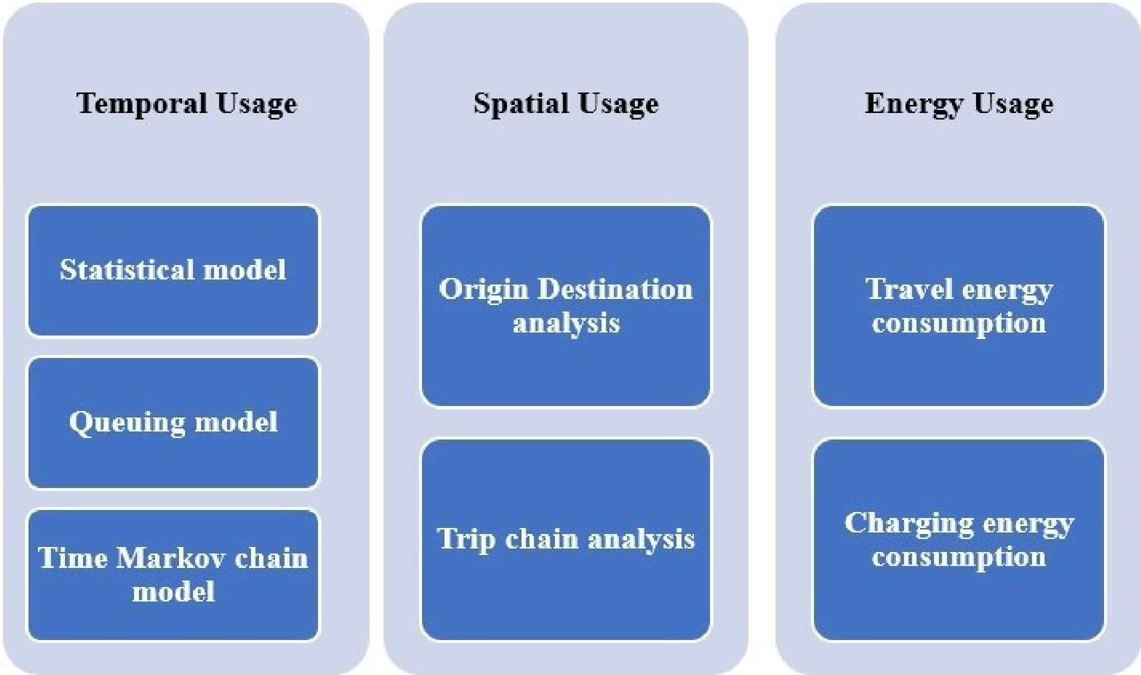

Figure 10. EV Usage models.

Energy usage modeling is also important for EV charging demand prediction, as temporal and spatial usage models are unable to obtain charging demand profiles without knowing the energy consumption of EVs. This can be again travel energy consumption or charging energy consumption.

A summary of the EV usage pattern models is presented in Table 2.

Table 2. Summary of EV usage pattern models [61].

Model	Sub Model	Description	Application
Temporal Usage	Statistical Model	Statistics/distributions of start/end time/duration	Inputs for charging demand simulation and other temporal usage models
	Queuing model	EV arrival rate and the numbers of charging EVs at assigned charging locations	Charging demand analysis of preassigned charging locations
	Time Markov Chain model	Transition probability matrices of vehicle state	Generate sequences of EV state over a period
Spatial Usage	Origin Destination analysis	Origin Destination matrices	Simulate spatial movements and trip destinations
	Trip chain model	Series of trip destinations and PDFs of departure/arrival time	Generate commuting patterns for multi-location demand estimation and charging scheduling
Energy Usage	Travel energy consumption	Travel distance, energy consumption rate	Calculate electricity demands of EVs
	Charging energy consumption	Charging power, charging time, charging efficiency	Charging power, charging time, charging efficiency

4.2. Siting and Sizing of EV Battery Swapping Station

Building BSS is very expensive. Therefore, a reasonable siting and sizing can not only provide excellent accessibility to battery swapping service for consumers, but also save a large amount of construction and configuration costs for BSS operators. The main factors affecting BSS siting and sizing are the technical ability of BSSs and the EV usage distribution and battery swapping habits of EV users. Service radius, traffic congestion and power capacity of local distribution network should be considered when determining the location and capacity of a BSS. An overview of the siting and sizing framework of BSS is shown in Figure 11.

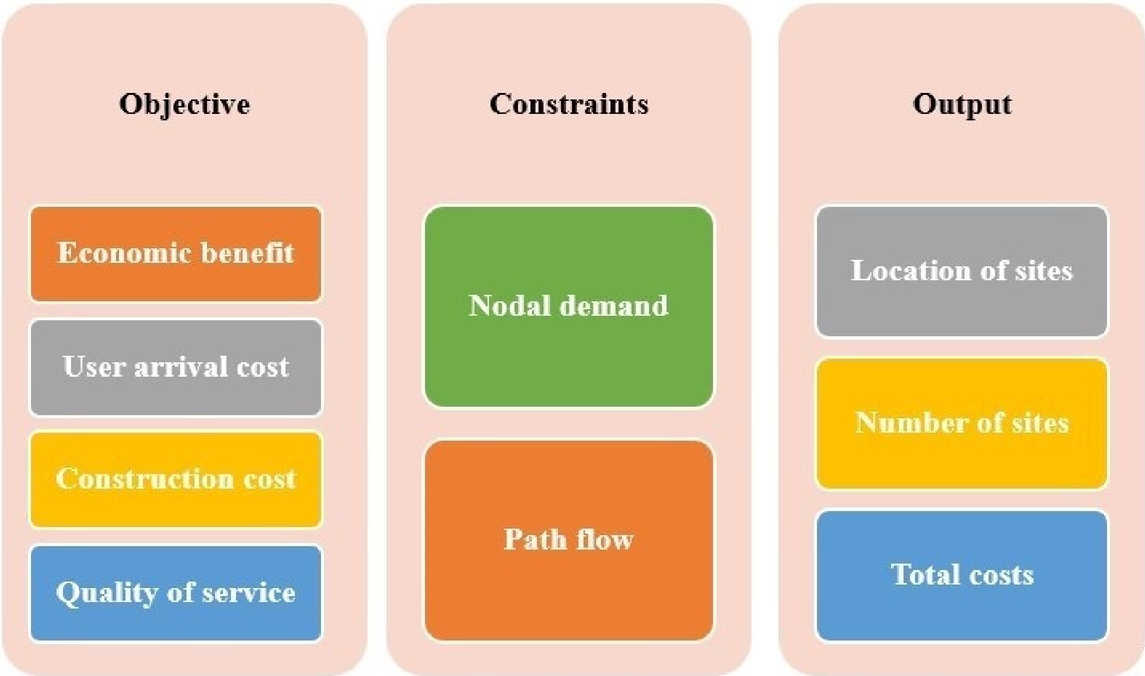

Figure 11. Siting of BSS [62].

5. Overview of RES Integration to Grid

Numerous environmental concerns have led to an uptick in the interest in RES such as solar and wind energy. However, when it comes to recharging zero-emission automobiles, wind power is by far the most popular option. This is an essential application of wind power.

According to the global wind report published by the GWEC in 2021, the objective for power system engineers in the future decade will be to create wind power plants with a greater capacity for production in order to mitigate the worst effects of climate change while simultaneously meeting demand. In the next decade, the entire global electricity production will be replaced by renewable energy, primarily wind power generation. Wind energy will provide a quarter of the non-conventional energy sources' overall output. As the utilization of wind power increases, conventional energy consumption will decrease, resulting in a greener environment. Consequently, greenhouse gas emissions can be decreased. Now is the moment for all of us to prioritize the utilization of renewable energy. Among all types of renewable energy, also known as clean energy, wind energy is currently gaining popularity due to its eco-friendly characteristics. However, the penetration level of wind power into a power system is difficult due to its randomness and uncertainty. The random character of the variance in wind power is a challenge for frequency management [63] and voltage quality [64].

6. Modelling and Decision Making

Compared with other forms of energy generation, wind energy generation is unpredictable, highly uncertain, and intermittent. Therefore, an efficient model is necessary for forecasting wind power. It must be as precise as feasible in order to reduce the consequences or repercussions of wind input on the grid. Only when EVs are parked can they be regulated; consequently, for load scheduling purposes. Awareness of their driving intentions is required. Human society is dynamic; hence, it is difficult to foresee its future.

The moving information of an EV comprises the arrival time, departure time, and driving distance. As there is a deadline to complete charging for every electric vehicle parking action, this procedure of charging the EV is time-sensitive. The future cost will depend entirely on the current pricing selection. In a multi-stage setup, we must therefore schedule the EV charging load. And, as the quantity of EVs increases, the curse of dimensionality issue manifests itself.

As detailed in the comprehensive identification of oysters with superior qualities that include unpredictability [65], the rigorous scheduling strategy is crucial for the current circumstance [66]. Wind energy's penetration into the electrical system [67] and the integration of conventional power plants [68]. In their respective literatures, the rigorous scheduling between charging electric vehicles and wind power is rarely described for clarity. Then, several authors formulated this topic as a stochastic problem that considers the performance strategy in a wind energy crisis [69]. The RSP identified a robust strategy to reduce the total cost in the most uncertain future scenarios. In their development, a probabilistic and parametric density function is used to characterize the wind power. In the preceding description, it was assumed that the parameter was perfectly familiar [70]. Currently, some have estimated the required parameter range, which is more pragmatic. A full description is provided. RSSP is an exceptional approach to the Markov decision process (MDP), in which the achievement of a process is the standard price over the unconditional development contingency [71]. When different levels of the unconditional development condition are autonomous [72]. When the uncertainties of the transition probabilities at distinct stages are independent, also known as the rectangularity property, the robust MDP can, in principle, be solved by robust value iteration and robust policy iteration [73]. However, the computational complexity of these approaches typically renders their employment in large-scale situations fruitless. Thus, proximal problem-solving techniques are in significant demand [74]. There are further methods [75], such as a rigorous scheduling mechanism that enhances the unconditional features of a chosen standard strategy.

In 2018, robust scheduling is considered in terms of the following results: (i) formulation of scheduling as a robust stochastic shortest path, where the goal aim is a sum of wind power utilization and cost of charging. (ii) enhancing the technique based on simulation technique for inclement weather (iii) the performance is quantitatively presented using actual wind and electric car data as a foundation and presenting an RSSP model for load supply matching to reduce charging costs and improve demand and supply balance. For various conditions, simulations and mathematical calculations are performed [76].

7. Impact of EV Integration to Grid

Table 3 summarizes the results of EV integration with the grid. The effect of EV charging on the ToU rates of the electricity distribution network was studied by the authors of [77]. The net load demand of the power grid increases due to recharging electric vehicles. ToU pricing is a practical method to move EV charging away from the highest demand time of day. Introducing ToU pricing has been shown to have a measurable effect on EV charging habits, and this effect has been quantified by the authors. The simulation results showed that the peak load may be lowered by 5% by using ToU rates. The current harmonic distortion caused by recharging electric vehicles is reduced from 4.88 percent to 4.03 percent thanks to a compensation-based harmonic reduction technique provided in [78].

Table 3. Research work on impact of EV on power grid.

Ref	Author	Year	Parameter	Diligence
[77]	Jones et al.	2022	Peak load	ToU rates reduced the peak load by 5%
[78]	Kazemtarghi et al.	2022	Harmonics	Active compensation based harmonic reduction technique that reduced the EV charging induced harmonic distortion in current from 4.88% to 4.03%

Table 3. *Cont.*

Ref	Author	Year	Parameter	Diligence
[79]	Singh et al.	2022	Voltage profile, Transformer loading	Impact of uncontrolled, smart, and V2G strategy on a residential power distribution network of Netherland
[80]	Qiu et al.	2022	Residential load demand	Empirical estimation of the grid impact due to in-home EV charging was different from that predicted by existing simulation models due to factors such as consumer behaviors
[81]	Pankaj et al.	2022	Harmonics, Voltage profile	With 1 EV, 20.30% of THD is produced, and with 3 EVs, 27.67% of THD is produced. Low voltage is also observed when more than one EV charger is connected at one phase
[82]	Alquthami et al.	2022	Load demand, power losses, voltage profile	Innovative model to generate the profiles of EV charging demand of Saudi Arabia and investigate the impact of charging on grid
[83]	Ding et al.	2022	Reward due to discharging	Bottleneck model considering trade off between waiting time cost and reward due to discharging
[84]	Rancilio et al.	2022	Tariff, Peak power, carbon footprint	By adopting smart charging at home the EV evening peak load can be reduced by 30% to 50%. Further, a 10% decrease in carbon footprint is achieved by valley-filling with work charging
[85]	Rahman et al.	2022	Voltage profile, harmonics, stability, power quality	EVs were modelled as mobile loads and was used as flexible resources
[86]	Mane et al.	2022	Transformer loading, Power factor, phase asymmetry, voltage profile	Modelled the impact of EV charger on LV residential network. Generally, nonlinear EV loads are connected to different phases, so there will be a phase asymmetry in the network. This asymmetry can be reduced by proper grid planning. Turning on and off of EV charger may impact the power factor that can be tackled by reactive power compensation
[87]	Deb et al.	2022	Voltage profile, power quality	Placing the EV load on weak points of the power distribution network and uncoordinated charging may be detrimental to smooth operation of the grid
[88]	Zaferanlouei et al.	2022	Voltage profile, transformer loading, congestion	Overloading of lines and transformers would take place when the share of EVs is above 20% for Norwegian grid
[89]	Sachan et al.	2021	Load demand, waiting time in the charging station	Modelled the charger placement problem by a game theoretic approach and analyzed the impact of charger placement on load demand and waiting time in the charging stations
[90]	Dechanupaprittha et al.	2021	Load demand, frequency deviation	Self-learning PSO based optimal EVs charging power control strategy considering the net charging power demand and frequency deviation to ensure smooth functioning of the grid
[91]	Ahmad et al.	2021	Harmonics, thermal limit, peak load	The voltage profile of the buses of the distribution network of Qatar was examined as the EV load increased to determine the capacity of the buses at certain THD levels
[92]	Khan et al.	2021	Voltage sag, load demand, power quality	Residential grid voltage sag increased by about 1.96% to 1.77%, 2.21%, 1.96 to 1.521% and 1.93% in four EV-charging profiles, respectively

Table 3. *Cont.*

Ref	Author	Year	Parameter	Diligence
[93]	Venegas et al.	2021	Peak load, charging frequency	An open-access agent-based EV simulation model was proposed including a probabilistic plug-in decision module developed and calibrated to match the charging behavior observed in the Electric Nation project
[94]	Qiu et al.	2021	Reliability	Simulated results showed that compared to the non-dynamic charging mode, the electric bus dynamic charging mode does not cause additional deterioration to the reliability indices such as SAIFI, SAIDI, and AENS
[95]	Mowry et al.	2021	Peak load, operational cost	Simulation results considering 3 million passenger EVs on the road showed that the system operational cost would rise by 8%. The rise in operational costs would be mostly due to transmission congestion of the feeder lines
[96]	Stiasny et al.	2021	Transformer loading, line loading, peak load, voltage profile	Grid operating parameters are most sensitive to number of vehicles, charger rating, and driver behavior modelling
[12]	Sachan et al.	2021	Voltage stability, reliability, power losses	Modelled the charger placement problem by Chicken Swarm Optimization (CSO) based heuristics and further analyzed the impact of charger placement on voltage stability, reliability indices, and power losses
[97]	Soofi et al.	2021	Voltage deviation, power quality	Second Order Cone programming (SOCP) formulation of the AC optimal power flow with the inclusion of EV and solar PV as distributed resources
[98]	Iqbal et al.	2021	Current harmonic emission, transformer loading, and voltage distortions	Analyzed the impact of EV charging on current harmonic emission, transformer loading, and voltage distortions of a low voltage residential grid. Further, they put forwarded a Monte Carlo simulation-based approach to model the EV usage
[99]	Slangen & Bhattacharyya	2021	Harmonics, Power quality, voltage profile	Harmonics, voltage variations and flicker were within the limits as given in EN50160. However, the chargers were a source of superharmonic currents at some specific frequencies. The impact on the grid voltage differed as per frequency
[100]	Archana & Rajeev	2021	Reliability	Modelled the charger placement problem with and without V2G considering a novel index called EV placement index that takes into account the voltage stability, reliability, as well as cost associated with EV placement
[101]	Akil et al.	2021	Peak load, line loading	Coordinated charging strategy for the EVs considering their dynamic behavior
[102]	Van den et al.	2021	Transformer loading	Predicted the future EV charging demand of an office complex in order to estimate the flexibility potential of EVs
[103]	Haider & Schegner	2021	Power quality, voltage profile, cable loading	Simulations showed that in urban networks EV integration would cause higher cable loading and in rural networks it would cause voltage drops

Table 3. *Cont.*

Ref	Author	Year	Parameter	Diligence
[104]	Sharma et al.	2020	Power quality	Comparative analysis of how common DC and AC bus architectures of fast chargers would impact the power quality of the grid
[105]	Sachan et al.	2020	Voltage profile, power quality	Compared different charging strategies and ranked smart charging highly to tackle the adverse impact of EV charging on grid
[106]	Deb et al.	2020	Voltage stability, reliability, power losses	Novel approach for charger placement considering cost, accessibility index, and VRP index
[107]	González et al.	2019	Peak load, voltage profile	Modelled the impact of EV charger on a Latin American grid and concluded that with 10% EV penetration the operational parameters of the grid would be least affected
[108]	Lillebo et al.	2019	Voltage profile, peak load	Simulations showed that the weakest power cable in the system would experience overload at a 20% EV penetration level. The network tolerated an EV penetration of 50% with regard to the voltage levels at all end-users
[109]	Deb et al.	2019	Voltage stability, reliability, power losses	Multi-objective formulation of the charger placement problem for Guwahati city considering cost, reliability, power
[110]	Fischer et al.	2019	Peak load	Stochastic bottom-up approach to analyze how EV charging would affect the load profiles
[111]	Deb et al.	2018	Voltage stability, reliability, power loss	System could sustain placement of fast charging stations at the strong buses up to a certain level, but the placement of fast charging stations at the weak buses of the system hampers the smooth operation of the power system
[112]	Kongjeen & Bhumkittipich	2018	Voltage profile	The lowest increased value of EV charging load had an effect on the load voltage deviation (0.062), the total active power loss (120 kW) and the total reactive power loss (80 kVar), respectively
[113]	Sachan	2018	Voltage profile, peak load	Smart charging strategies are beneficial and could contribute to less voltage violations and cost savings
[114]	Lin et al.	2018	Peak load	Proposed a multi-agent system to simulate the interaction of EVs in energy hub with different penetration rates and charging pattern
[115]	Deb et al.	2017	Reliability	After placement of fast charging station with 30 servers at bus 11 which was the strongest bus of the system the SAIFI increased to 0.1080 interruption/yr. SAIDI and CAIDI value also increased to 0.5374 h/yr and 5.2481 hr/interruption respectively

The effect of electric vehicle chargers on the voltage distribution network in a home was investigated in [79]. Evidence from public chargers in the Netherlands was used to model the charging process. The analysis of the consequences was done in three different cases. Uncontrolled charging was studied first, followed by smart charging, and finally bidirectional V2G. The simulations showed that the network performance metrics were suitable for a high density of EVs per charger. Nevertheless, an increase in the number of electric vehicles using a single charger will cause long wait times and irritate EV owners.

In addition, it was discovered that clever charging procedures will raise the transformers' maximum loading.

The authors of [80] looked at the environmental effects of home EV charging in Arizona, USA. In this study, we looked at information from the smart meters of around 1600 residences that have electric vehicles. The demand for residential load was shown to rise by 7–14% if EV charging occurred during summer peak hours (6 PM to 8 PM). It was also noted that most EV households responded to energy price signals by boosting their charging activity during off-peak hours when the ToU pricing was at its most affordable for EVs. Furthermore, consumer behavior and other factors accounted for discrepancies between existing simulation models and the actual estimation of the grid impact due to in-home EV charging.

To determine how EV charges affect harmonics, the writers analyzed the data presented in ref. [81]. According to the authors, harmonics rise as the number of EV charges grows. One EV results in 20.30% of THD, while three EVs result in 27.56% of THD. When more than one electric vehicle charger is plugged into the same phase, the voltage drops.

The authors of ref. [82] suggested a novel methodology to construct the profiles of EV charging demand that takes into account the driving patterns of EVs, energy consumption, and charging schedules. To test how charging electric vehicles would affect the electricity grid, a simulation was run using the suggested EV demand model. Saudi Arabia's distribution system was used to verify the model.

The authors of ref. [83] offer a bottleneck model to examine the effects of the bidirectional discharging by V2G method on waiting times and traffic congestion. The model also took into account the potential loss owing to waiting time versus the potential gain due to discharge.

The influence of smart charging on tariffs, peak load reduction, and carbon footprint reduction is investigated in ref. [84]. They concluded that 30% to 50% of the nighttime peak load for EVs might be avoided if more people used smart charging at home. Furthermore, through valley-filling with work charging, a 10% reduction in carbon footprint can be accomplished.

The effects of EV charging loads on power grid parameters such as voltage profile, stability, power quality, and harmonics were investigated by the authors in [85]. Opportunities for EVs to be used as a flexible resource were also explored, and EV loads were modeled as mobile loads.

The authors of ref. [86] looked into the viability of the current system for accommodating EVs. Grid factors such as transformer loading, power factor, voltage profile, and phase imbalance were examined to see how they might be impacted by the increased loading caused by EV charging. The authors have simulated how EV chargers will affect the LV home network. There will be phase asymmetry in the network because nonlinear EV loads are usually connected to separate phases. A strategic grid layout can mitigate this disparity. The power factor may be affected by the frequent on-and-off cycles of an electric vehicle charger; however, this is something that may be addressed through reactive power correction.

Using data from a sample of India's urban distribution networks, the authors of [87] studied how EV charging loads altered the voltage profile and power quality. They came to the conclusion that uncoordinated charging and concentrating the EV load on power distribution network weak spots could be harmful to grid stability.

Several charging scenarios, including "dumb" charging, "coordinated" charging without network con-straits, and "coordinated" charging with network limitations, were examined for their effects on the Norwegian grid by the authors of ref. [88]. It was determined that if the percentage of EVs on the road increased above 20%, there would be over-loading of wires and transformers.

The authors of ref. [89] modeled the charger placement problem using a game-theoretic method and investigated the effect of charger placement on load demand and waiting time at charging stations. Guwahati, a city in northeastern India, was used to verify the model's accuracy for its distribution network.

In order to keep the power grid running smoothly, the authors of ref. [90] developed an optimal charging power control method for electric vehicles (EVs) that uses a self-learning PSO to consider both the net charging power demand and the frequency deviation.

The effects of electric vehicle (EV) charging on Qatar's distribution network were studied in ref. [91]. Several scenarios of electric vehicle penetration into the distribution network were modeled in Simulink. With the goal of establishing the buses' capacity at a given THD level, the voltage profile was analyzed as the EV load rose.

By considering factors including charging duration, charging technique, and vehicle characteristics, the authors of [92] were able to assess the effects of widespread EV penetration on low voltage distribution. Observations made during the rapid charging and discharging of EVs showed that bus voltage and line current were impacted. In four EV-charging profiles, the residential grid voltage sag increased by 1.96%, 1.77%, 2.21%, and 1.96 to 1.521%, respectively.

In [93], the authors investigated the potential of EV fleets as a flexibility resource by analyzing the impact of both regular and irregular (not charging everyday) charging behavior on the grid. The Electric Nation project inspired the proposal of a new type of open-source agent-based EV simulation model, complete with a probabilistic plug-in decision module designed and calibrated to mimic real-world charging patterns. The average number of times an EV user plugs in their vehicle each week was calculated to be between two and three. The proposed agent-based model's results demonstrated that unlike when EVs are charged concurrently, when users aren't being systematic about plugging them in, the impact of EV charging is reduced, especially when charging in response to price. Non-systematic plug-in, however, can limit options, especially in light of recent trends toward ever-larger battery capacities.

The effects of dynamic wireless charging of electric buses on the power grid were studied by the authors of ref. [94]. In order to study how charging electric buses wirelessly will affect the power system, a dynamic model was developed. The dynamic charging mode of the electric bus was found to have no negative impact on dependability indices such as SAIFI, SAIDI, and AENS in simulations compared with the non-dynamic charging mode.

There was an examination of how highway fast chargers affected the electricity grid in ref. [95]. The operational cost of the system was predicted to increase by 8% in the simulation with 3 million passenger EVs on the road. The main cause of the increase in operating expenses would be transmission congestion on the feeder lines.

In ref. [96], authors modeled how recharging EVs might affect parameters of the low voltage distribution grid such as line loading, transformer loading, peak load, and voltage profile. The authors also conducted a sensitivity analysis and found that the number of vehicles, charger rating, and driver behavior model-ling have the greatest impact on grid operating parameters.

The authors of ref. [12] modeled the charger placement problem using heuristics based on Chicken Swarm Optimization (CSO), and then they examined the effect of charger placement on voltage stability, reliability indices, and power losses.

Rapid EV charging was studied for its effect on the IEEE 33 bus test network in ref. [97]. They reasoned that the voltage profiles of the buses would be affected by the charging levels. To further incorporate EVs and solar PV as distributed resources, they suggested a Second Order Cone Programming (SOCP) formulation of the AC optimum power flow.

In ref. [98], researchers examined how charging electric vehicles affected the current harmonic emission, trans-former loading, and voltage distortions of a low-voltage residential grid. In addition, they proposed a Monte Carlo simulation-based method for modeling EV utilization.

The authors of ref. [99] studied data from a field trial of electric bus charging that took place in real time. After careful analysis, they determined that the levels of harmonics, voltage fluctuations, and flickering were all well within the standards set out by EN50160. Yet, at some frequencies, the chargers produced currents that were themselves super harmonic. Grid voltage was affected differently depending on frequency.

In ref. [100], authors modeled the charger placement problem with and without V2G considering a novel index called EV placement index that takes into account the voltage stability, reliability, as well as cost associated with EV placement. Further, the authors have simulated how the placement of chargers in the real time distribution network of Kerala, India, would impact the typical power system operating parameters such as voltage stability, harmonics, and reliability indices.

In ref. [101], authors proposed a coordinated charging strategy for the EVs considering their dynamic behavior. They also quantified the impact of the proposed strategy on power system parameters and concluded that a coordinated charging scheme has a lesser impact on the power network.

In ref. [102], authors focused on predicting the future EV charging demand of an office complex in order to estimate the flexibility potential of EVs. Thof low voltse consisting of real transaction data for 42 EVs charging for over a year at Utrecht Science Park, Utrecht, the Netherlands. The simulations showed that in 2050, 4 out of 7 studied transformers would be overloaded. Further, they concluded that around 50% of the EV demand can be delayed for more than 8 h. When this flexibility is used, overloading of 3 out of 4 transformers could be mitigated.

In ref. [103], authors analyzed how EV integration with the grid would cause overloading of the low voltage networks. A number of low voltage networks were modeled using DigSilent Powerfactory, taking into consideration the s variability of household electricity consumption, EV usage, and solar irradiance. Simulations showed that in urban networks, EV integration would cause higher cable loading, while in rural networks, it would cause voltage drops.

In ref. [104], authors provided a comparative analysis of how the common DC and AC bus architectures of fast chargers would impact the power quality of the grid.

In ref. [105], authors compared different charging strategies and ranked smart charging highly to tackle the adverse impact of EV charging on the grid.

In ref. [106], authors proposed a novel approach for charger placement considering cost, accessibility index, and VRP index. VRP index has the capability to consider the impact of EV charger on voltage stability, reliability, and power loss under a single framework.

In ref. [107], authors modeled the impact of EV chargers on a Latin American grid and concluded that with 10% EV penetration, the operational parameters of the grid would be least affected.

The impact of increased EV adoption on the Norwegian electrical grid was examined by the authors of ref. [108]. Calculations revealed that at a 20% EV penetration level, the system's weakest power cable would be overloaded. There was a 50% EV penetration into the network without any noticeable changes in voltage at any of the end-users.

As an example, in ref. [109], the authors simulate the charging infrastructure placement problem in the context of Guwahati city, India, and discuss the effect of charger placement on the voltage stability, dependability, and power losses of the city's streamlined power network.

Authors in ref. [110] used a stochastic bottom-up method to examine the impact of EV charging on load profiles. Filtering by demographic and economic characteristics, they examined a massive dataset of German mobility consisting of 70,000 car trips. It was determined that, depending on the loading infrastructure, the peak load may increase by a factor of 8.5. Meanwhile, peak demand would grow by a factor of around three, and yearly electricity consumption would roughly quadruple.

In ref. [111], the authors examined the effects of EV charging demand on a typical IEEE 33 bus distribution network across six different scenarios involving the placement of EV chargers. It was found that rapid charging stations may be placed at the strong buses up to a specific level without negatively impacting the operation of the power grid, but that placing such stations at the weak buses would have a negative effect.

The voltage profile of an IEEE 33 bus distribution network was investigated in [112] to determine the effects of a charging load for electric vehicles. The load voltage deviation

(0.062), total active power loss (120 kW), and total reactive power loss (80 kVar) were all influenced by even the smallest increment in EV charging load.

According to the findings presented in [113], various charging procedures can have a significant effect on a power grid. The benefits of smart charging solutions are discussed, including their potential to reduce voltage violations and cut down on expenses.

The authors of [114] suggested a multi-agent system to model the behavior of electric vehicles (EVs) charging at an energy hub where the penetration rate and charging pattern of the EVs vary. Vehicle-to-grid (V2G) connectivity, rapid charging (RCP), and smart charging (SCP) were all simulated. At 20% increments, the percentage of households using electric vehicles rose from 10% to 90%. When compared with a scenario without EVs, peak demand increases by 3.4% to 17.1% under the UCP. The SCP moves the EV charging load to the valley period, so the EH's energy dispatch between 07:00 and 23:00 is unchanged from the reference scenario. The highest grid electricity demand occurs when V2G is considered; for instance, the demand with 50% PR is twice the grid electricity demand in the reference situation.

Researchers in [115] examined the effects of adding EV chargers to the load of the IEEE 33 bus test network using standard reliability indices such as SAIFI, SAIDI, and CAIDI. In the baseline scenario, SAIFI was estimated to be 0.0982 interruptions per year. The SAIFI went up to 0.1080 interruptions per year when a rapid charging station with 30 servers was installed on bus 11, the system's strongest bus. In addition, the SAIDI and CAIDI values rose to 0.5374 and 5.2481 h per year and interruption, respectively.

8. Impact of RES Integration to Grid

Table 4 summarizes the results of RES integration to the grid.

Table 4. Research work on impact of RES on power grid.

Ref	Author	Year	Parameter	Diligence
[116]	Wang et al.	2022	energy bases and load centers	Enhances power generation of renewable energy source
[117]	Shiwei Yu	2022	Direct current (DC) and alternating current (AC) transmission technologies	Increased power transfer capability
[118]	Bhattacharya et al.	2021	marine renewable energy	Marine renewable energy resources are more available and persistent
[119]	Akhtar et al.	2021	Fault analysis	Risk assessment of restructured power system with integrating the electric vehicles and renewable energy resources
[120]	Hanni Wirawan et al.	2021	Rural electrification	An off-grid renewable energy-based electricity rollout to alleviate rural poverty in Indonesia's remote islands
[121]	Mark et al.	2021	Energy	Stable grid
[122]	Mokeke, Leboli Z et al.	2021	Voltage, frequency and rotor angle	increased penetration of the intermittent (variable) renewable energy generators (IREGs) led to grid instability
[123]	Ayadi et al.	2020	Smart grid	Efficient Energy management
[124]	Oyekale et. al	2020	Renewable hydrogen	Cheaper energy storage devices
[125]	Alam et al.	2020	Energy storage devices, and fault current limiters	high-level RES grid integration issues
[126]	Poul Alberg et.al	2020	Energy systems	Energy system integration, effects, and environmental performance are analyzed.

Table 4. *Cont.*

Ref	Author	Year	Parameter	Diligence
[127]	G. Sokhna Seck	2020	Energy	Power exchanges with neighbors with higher share of renewable energy systems in the power production
[128]	Ali et al.	2020	Energy	Improved stability
[9]	Johnson et al.	2020	Electricity generation	Improved stability
[129]	Samuel C. Johnson	2020	Grid operation	non-synchronous energy generation
[130]	Keck, Felix	2019	Energy	Stability Improved
[130]	Worighi et al.	2019	Energy storage system	Improved installed capacity
[131]	Ndamulelo et al.	2019	Grid-connected variable renewable energy	Examines generator type, penetration, and grid features of international VRE integration
[30]	Samuel et al.	2019	Energy	Improved grid stability
[132]	Madeleine McPherson et al.	2018	Energy	Improved stability
[133]	Perera et al.	2017	Energy	Improve grid stability
[134]	Musau et al.	2017	Energy	This reduces generation costs and pollution
[135]	Triviño et al.	2017	Smart grid	Voltage improvement
[136]	Harrouz et al.	2017	Energy	Grid voltage improvement
[137]	Schmietendorf et al.	2017	Energy	Increased grid reliability

Transition regression panel smoothing reflects the regional effects of grid-connecting renewable energy sources, as studied by the authors of ref. [116]. In energy bases and load centers, higher voltages generally have a more beneficial effect on renewable energy output and consumption, but this is not always the case. Ultra-high voltage systems are unaffected by the incorporation of renewable energy sources into the grid. No renewable energy source is currently feasible due to the lack of extra-high voltage power lines serving as the backbone of the national grid. The power grid needs to be modernized immediately.

In ref. [117], we determine the optimal line path, transmission capacity, and development schedule for six inter-regional transmission lines. By 2039, transmission from the northwest to the east will increase by 265%, while transmission from the north to the center will increase by 160%. The current standard of 400 kV DC (5 GW) will be replaced by 800 kV DC (10 GW) in 2033. The highest construction years are 2036–2039. Renewable wind and solar power are generated in central and eastern China. Increases in wind and solar electricity are expected to treble by the year 2039. By disconnecting lines 2–6 and 7–9, energy storage and demand-side response can increase renewable power on the grid by 1.7% and 2.6%, respectively.

Based on their findings, the authors of ref. [118] concluded that marine renewable energy resources are consistently more available and persistent than wind and solar on an hourly basis during the whole year of operation. There is also speculation that using wave resources can reduce the amount of balancing effort required by electrical grids.

The method presented in [119] combines the encouraging effects of a Gaussian distribution with the probabilistic breakdown of many components' failure rates inside a fuzzy fault tree framework. System switches and low power components were not detectable by traditional fault tree analysis. The possibility of power disruptions is also ignored. Lack of data causes significant failure and poor behavior forecast uncertainty for grid-connected wind energy power systems and EV installations.

In order to determine if rural electrification through renewable energy village grids (RVGs) may alleviate poverty in off-grid villages and islands in Indonesia, the authors of [120] conducted an in-depth study. This research looks at how the use of renewable off-grid electricity could help alleviate poverty and security concerns in far-flung areas. Energy production is constrained by geography. DID compares the outcomes of treatment and nontreatment in 217 remote villages in Indonesia. Ninety-one people from marginal socioeconomic backgrounds were wiped out by the program. This research also found that providing small businesses in the hamlet with access to electricity helped reduce poverty. The use of renewable energy to power homes off the grid has helped alleviate poverty on Indonesian islands.

Using a scenario in which every country in Western Europe relies only on renewable sources of energy such as wind, water, and sunlight, the authors of [121] examine the effects of interconnecting vs. isolating their electric networks on energy costs and demand (WWS). Wind, sun, thermal loads, and refrigeration loads can all be predicted with the use of weather models. World Wide Solar Power, Storage, Demand Response, Power, Heat, Cold, and Hydrogen are all balanced by grids. The United Kingdom, France, Germany, Spain, Italy, and Spain all have dependable options, as do Luxembourg and Gibraltar. Energy pricing, generator/storage overbuilding, energy shedding, and land/water demands can all be reduced through interconnected nations. Electrical costs in Western Europe might be reduced by up to 13% if the region were linked. The most significant reduction in emissions occurs when Denmark (20.6%) and Northwestern Europe (13.7%) are connected to Norway’s abundant hydropower. Connections between Luxembourg and larger states are advantageous for everyone. Countries such as France and Germany, among others, have the financial means to switch to 100% WWS grids.

Utility-scale PV and wind farm integration is being driven by the need for sustainable power systems. Wind and solar photovoltaic (PV) systems are distinct from traditional power plants in that they generate their own electricity [122]. Lesotho’s electricity supply is unstable due to intermittent renewable energy production (IREGs). The majority of PV and wind generators were located at the Ha-Ramarothole and Letseng substations. Research on the dynamic effects of changes in renewable energy capacity used a short circuit defect at the bus bar with the shortest critical clearance time (CCT) to quantify changes in voltage, frequency, and rotor angle. Study of steady-state voltage with hourly load data, IREG data, and Muela Hydropower generation for 2018. The stability of voltage, frequency, and rotor angle was measured by the Lesotho Grid Code.

With the current energy problem, renewable energy sources are expected to replace traditional power plants within the next several decades, as discussed in [123]. Therefore, the focus of the present research is on finding ways to integrate renewable energy sources into the smart grid. This research explains the advantages and disadvantages of using various control systems, all of which have played a role in the efficient incorporation of renewable energy sources.

The consequences of renewable energy technology grid integration on power network efficiency and the most prevalent approaches to addressing these issues are summarized in [124]. Renewable energy can be obtained from the sun, the wind, biomass, geothermal heat, and renewable hydrogen/fuel cells. Many global energy projections have incorrectly stated that renewable resources can provide global energy needs in the thousands. This is because of limitations in the actual use of these resources. For a comprehensive summary of these challenges and workable answers, this review research is essential.

In the last two decades, RESs have become increasingly commonplace [125]. Without regular synchronous generators, the system has less inertia, making regulation more difficult. High uncertainties, low fault ride through capability, high fault current, limited generation reserve, and poor power quality are just some of the technical difficulties that arise from RESs integration. Solar and wind power are risky because of the unpredictability of the sun and the wind. In order to address these problems, cutting-edge technologies have been developed for control, optimization, energy storage, and limiting fault currents.

The report analyzes the systemic challenges associated with integrating RES into grid infrastructure. Answers to the challenges are being discussed. The problems with and potential solutions for combining wind and solar energy are extensively documented. Lastly, some considerations for renewable energy integration are given for experts in the field and academics.

With an eye toward technology, availability assessment, and system integration, the authors of ref. [126] examine the current state of renewable energy studies. Renewable energy sources such as wind, waves, geothermal heat, solar power, and electricity, and salinity gradient systems are discussed. Environmental performance, environmental consequences, and the integration of energy systems are evaluated in the last section. This review provides a broader context for the research presented at the Sustainable Development of Energy, Water, and Environmental Systems (SDEWES) conference series and published in Special Issues of many journals.

The writer of ref. [117] examined the current state of the renewable energy study, concentrating on technological advancements, availability evaluations, and system integration. Technology using wind, waves, geothermal heat, solar power, and electricity, and electricity generated by a salinity gradient are discussed. Integrating energy systems, their consequences, and their impact on the environment are evaluated at the end.

The short-term performance of the French electrical grid is the subject of a long-term prospective study in France. After Re-union Island, countries that rely heavily on electricity look at their infrastructure and evaluate its adequacy and temporary stability. The TIMES-FR Energy System Optimization Model uses kinetic reserves as a reliability metric for the French power sector (ESOM). Modular renewable energy backup stabilizes power systems. Consistency is guaranteed at 65% VRE. The highest hourly VRE for 100 EnR reliable power generation was 84%. Completely relying on renewable energy sources (RES) would triple new installed capacity between 2013 and 2050, significantly improving the reliability of the system. To meet the dependability need at any time by providing the system with greater inertia, it is important to think about thorough upstream planning and flexible solutions such as demand-response, storage technologies, linkages, or replacement or new facilities. Emphasize electricity trades with neighbors who are producing renewable energy [118].

Integration and renewables, as the authors of ref. [119] showed, pose a threat to the reliability of the electricity grid. Grid connectivity was disrupted when wind and solar PV replaced traditional power plants. Grids are made more reliable by modern technology. The integration of renewable power plants and regulations for their use are reviewed here. Requirements for grid stability are compared, including voltage stability, frequency stability, voltage ride-through (VRT), power quality, and active and reactive power regulations. Controls. In this research, cutting-edge methods of regulation and control are weighed and compared. Overall, the study finds that integrating requirements enhances grid operation, stability, security, and reliability; however, protective rules, global harmonization, and control optimization all need improvement. Limitations on the use of RES. Developers and researchers could benefit from this review. Assist power grid operators worldwide in creating uniform electrical standards.

According to ref. [120], current energy needs far exceed those met by more traditional means. The use of electricity is crucial to technological advances. Most pollution associated with energy generation comes from burning fossil fuels. Electricity supply and demand mismatches can be closed by renewable energy. A decrease in carbon dioxide emissions (GHG). Energy production is based on location. Power quality, reliability, stability, harmonics, single-phase oscillations, and reactive power adjustment could all be impacted by the incorporation of RES into the grid. The problems with RES interruptions are eliminated when an ESS is integrated. Ecology-friendly power Increasing the reliability, effectiveness, and energy density of renewable energy generation systems is the focus of RES-ESS innovation.

Traditional energy sources are insufficient to supply the world's energy demands [121]. Electricity is the lifeblood of today's manufacturing and scientific communities. The vast majority of us rely on fossil fuels for our energy needs. The gap between electricity supply and demand could be closed by renewable energy. Carbon Dioxide Produced by the Energy Sector (GHG). Energy generation is based on consumption. Reactive power correction, RES integration, and power quality/reliability/stability/harmonics/single-phase overcurrent could be negatively impacted. The underutilized RES and ESSs help out. absolutely safe for use by anyone. ESS/RES. The power density, efficiency, and dependability of RES power systems are all improved by ESSs. The effectiveness of PV systems is diminished by harmonic overtones. Control strategies using multiple FACTS types have an impact on RES-based power grids. In order to integrate RES into electricity networks in a secure manner, FACTS are required.

Given the flexibility EES provides the power network, it may one day be possible to make the switch to clean energy, as demonstrated by [122]. Many professionals acknowledge EES's value, but many express concern about its unpredictability in key areas such as technology, price, business strategies, and market architectures. Cost-benefit studies of EES for zero-emissions electricity generation are performed here. The effects of adding EES to wind and solar generation on LCOE, installed capacity, generation mix, and energy spillage are investigated in a GIS-supported hourly simulation study of Australia. There is a reduction in LCOE when EES is used in settings with high penetration of renewable energy sources. Costs of less than one thousand Australian dollars per megawatt-hour make 90–180 GWh of EES a practical option in Australia. In addition to reducing LCOE by 13–22%, 22–23% of installed capacity, and 76% of energy loss, the study finds that EES can improve efficiency. The generation mix is profoundly impacted by EES deployment.

Variable renewable energy (VRE) systems that are connected to the grid have been growing rapidly in recent years [123]. The addition of more of these devices complicates plans to upgrade regional power grid infrastructure. The high VRE regional power networks were analyzed. Renewable resources, VRE goals, and grids vary by region. The study of VRE integration is primarily conducted on a regional scale. Since it would be impractical and prohibitively expensive to do comprehensive VRE integration studies for every grid, it is essential to narrow the scope by identifying anticipated regional difficulties. This research looks at the many types of generators being used around the world, as well as their penetration rates and how they interact with the power system. The integration of VREs offers regional advantages.

It is clear from ref. [124] that renewable energy sources such as wind and solar threaten grid reliability. The purpose of this study was to determine under what conditions, in terms of frequency contingencies such as generator outages, an electric system would be more vulnerable in the presence of a high penetration of renewable energy sources. By proxy, system inertia was evaluated using unit commitment and dispatch modeling, and grid stability was measured. A case study of Texas' grid showed how this could be done. Modeled scenarios showed that the Texas grid can adapt to significant changes, even with a high penetration of renewable energy (30% of energy generation, up from 18% in 2017). Without the addition of nuclear power plants and exclusive-use networks, the model exhibits unstable inertia. To preserve system inertia, our model ran a large number of coal and natural gas combined-cycle facilities at part-load or the lowest operational level possible. If the share of renewable energy increases, this could affect other electrical grids that rely on synchronous generators for inertial support.

A rise in variable renewable wind and solar resources [125] necessitates a rise in demand response, dispatchable power, transmission connectivity, and storage. In this piece, we look at how to measure the value of storage facilities in terms of their production costs. There is still a need for storage for non-renewable energy sources since they are so inflexible, even at low levels of renewable energy penetration. For high penetrations of renewable energy, storage is essential for flexibility. The rate at which storage assets are used is affected by factors such as the proportion of renewable energy sources in the energy system, the format of the bidding process, and the ownership model. Consumption of storage assets will occur at cheaper times and production at more costly times regardless of the bidding structure, but the largest price differential can be achieved by the central authority bargaining for price arbitrage. The value of storage is based on system adaptability, renewable energy share, and competitive bidding.

Traditional generators and rotational systems are being phased out in ref. [126] in favor of grid-connected wind and solar PV. The price of electricity and pollutants is lowered as a result. The frequency dynamics are accelerated by low inertia, which might be detrimental to stability. Both frequency regulation and stability are hampered as a result. Complete blackouts can be caused by destructive vibrations (DV) and under frequency load shedding (UFLS) if the frequency variation is particularly large. Grid expansion in Kenya was aided by renewable energy sources such as wind and solar. When a monkey accidentally tripped a transformer at the Gitaru Hydroelectric Power Plant at 11:30 a.m. on Tuesday, 7 June 2016, the entire country lost power. In order to better understand frequency instability with RE, this work revisits UFLS and proposes the concept of Combined Fre-quency with Renewable Energy Storage Cost (CFS). Recaps the Kenyan Court Scandal.

Renewable energy sources (RES) [127] are crucial to the operation of smart grids. The effect that renewable energy has on the electrical grid is determined by the nature of the source, its penetration rate, and the design of the grid. In this study, we analyze the effect of renewable energy sources on a measurement of power quality (voltage dips). Consider the Italian grid and its structure. Considering how renewable energy sources and grid connectivity can change from region to region, this concept is intriguing. In this study, we test the hypothesis that the Pearson's index and the *p*-value have a linear relationship. Less voltage drops mean more renewable energy sources. We disprove this assumption.

Issues with increased demand for electricity from the grid are described in ref. [128]. Standardized resources can't keep up with consumer need. It's clear that, in this case, renewable energy is the most economical and beneficial option for satisfying household power demands. The quality and security of renewable energy systems are enhanced through the use of information and communication technology in a smart grid. The potential of renewable energy sources in Algeria is analyzed.

Changes in renewable energy inputs threaten grid reliability, as stated in ref. [9]. Inefficient load balancing and self-organized synchronization lead to short-term oscillations in such systems. During these times, electricity generated by wind and solar is unpredictable and not Gaussian. Using Kuramoto's power grid model, we investigate the effects of short-term wind changes on desynchronization, frequency, and voltage quality. Changes in the feed-in are represented by a temporal correlation, a Kolmogorov power spectrum, and intermittent increases. We discovered that correlations are required to capture the probability of severe outages, but the intermittent nature of wind power has significant effects on power quality, as the intermittency is directly transferred into frequency and voltage fluctuations, leading to a novel type of fluctuations that is beyond engineering knowledge.

9. Challenges of EV Integration to Grid

The safe operation of the power network may be compromised with the increasing EV numbers. EVs have the capacity to serve as additional load as well as distributed flexible load. The challenges imposed by the grid integration of EVs can be divided into power issues, energy issues, and grid reinforcement. A summary of these challenges is presented in Table 5.

Table 5. Challenges of EV integration to grid [138].

Use Case	Locations	Power Issues	Energy Issues	Grid Reinforcement
Public slow charging	Street parking, Social/recreational areas, Park & Ride	For multiple installations, significant impacts can be expected in Secondary Substations (MV/LV transformers)	No significant issue	It could be necessary to replace MV/LV transformers and/or MV and LV feeders

Table 5. *Cont.*

Use Case	Locations	Power Issues	Energy Issues	Grid Reinforcement
Home private charging	Single houses, apartments, hotels, offices	Voltage issues can be expected in rural areas	No significant issue	It could be necessary to replace MV/LV transformers and/or MV and LV feeders
High Power Chargers—"Fuel Station" Model	Fast chargers (50–150 kW) in existing fuel stations	Single installations may require a significant increase of power absorption	Energy withdrawal from the network could be significant	It could be necessary to install a dedicated MV substation with additional cost and time. MV lines (and in some cases, MV/LV transformers) could need to be replaced
Urban hyper hubs	Hyper fast chargers (150–350 kW) in new dedicated areas designed for cars in urban areas	Loads generated by EV charging add up to other LV and MV loads. The impacts could be significant, also on MV lines	No significant issue	MV lines (and in some cases, MV/LV transformers) could need to be replaced
Bus depots	High number (tens/hundreds) of buses performing night charging	A single deposit could require 5–10 MW, often in urban areas. There is a strong need for coordination between grid operators and local public transport operators	Moderate additional energy demand	In the event of the high number of buses, new primary substations could be required
Highway hyper hubs	Hyper fast chargers (150–350 kW) in new dedicated areas on highways both for cars and for heavy duty vehicles	A single hub could require more than 10 MW, often in rural areas. There is a strong need for coordination with grid operators in order to locate hubs close to existing HV lines	Energy withdrawal from the network could be significant but no issues are expected	A new Primary Substation would be required. A well-planned location would minimise the need for new HV lines
Company fleets	Pool vehicles (utilities, public services, private companies)	For multiple installations, significant impacts can be expected in Secondary Substations (MV/LV transformers)	No significant issue	It could be necessary to replace MV/LV transformers and/or MV and LV feeders

10. Challenges of RES Integration to Grid

Integrating RES to the grid may have several challenges such as flicker, harmonic distortions, narrow voltage trips as listed in Table 6.

Table 6. Challenges of RES integration to grid [139].

Category	Challenges
Quality	Increasing flicker Increasing harmonic distortions Unreliable shut down during blackouts Increasing local voltage excursions
Flow	Missing distribution grid capacity Increasing volatile flow patterns from lower grid levels Inadequate protection design Increasing short circuit current Narrow voltage trip details Missing transmission grid capacity

Table 6. *Cont.*

Category	Challenges
Stability	Insufficient reactive power provision Decreasing level of short circuit power Decreasing level of inertia Inadequate coordination of frequency and voltage trips limit
Balance	Insufficient short term generation adequacy Insufficient forecasting of variable RES Insufficient firmness of variable RES generators

11. Optimization Techniques for EV and RES Integration to Grid

11.1. Optimization Techniques for EV Integration to Grid

The research works on applications of optimization techniques for integrating EV to the grid are elaborated here.

Zhang et al. proposed a wind energy reduction usage strategy that utilizes the use of electric vehicles (EVs) with the aim to minimize the variations in wind power output by utilizing a hybrid algorithm called Implementation of Differential Evolution Quantum Particle Swarm Optimization (IDE-QPSO). The technique starts with a charging load demand for EVs. The second step is to use an enhanced particle swarm optimization algorithm to explain a multi-objective optimization framework that takes into account the utilization of wind energy shortfalls while also minimizing the intensity and variability of wind energy output. S sufficient modelling trials demonstrated that this method may successfully mitigate the impact of wind power production variability while simultaneously increasing the efficiency with which wind power is used [140].

Huy et al. introduced a comprehensive Home Energy Management System (HEMS) framework that incorporates Electric Vehicles (EVs) and employs a Multi-Objective Mixed-Integer Linear Programming model. The model is designed to optimize various parameters, such as energy costs, peak-to-average ratio (PAR), and discomfort index, while also maximizing vehicle-to-home and home-to-grid capacities (DI)In addition, a strategy for integrating the enhanced-constraint to efficiently tackle any multi-objective HEMS issues is described. Multiple computations employing both deterministic and stochastic scenarios are used to verify the suggested method [141].

Li et al. presented in their research a layered control system for plug-in hybrid electric vehicles to reduce their fuel usage. In the optimization method, two kinds of powertrain concepts are utilized initially. Using convex optimization, an approximation of a model is applied in the higher control layer to obtain the optimum baseline state of the charge trajectory. Consequently, at the deeper control plane, the fuel usage is reduced in real-time utilizing a high-fidelity powertrain framework and integrating the corresponding consumption minimize method into the adaptive control scheme. Furthermore, optimization findings from the remaining three real-time control techniques and two prospective energy management techniques are provided and examined to validate the suggested method's efficacy [142].

Wang et al. examined EV and proposed an effective co-optimization technique in order to concurrently identify optimum battery pack and turbine-generator pack sizes and appropriate control parameters. To design an objective function, the starting mass, fuel usage, and battery deterioration are selected as optimization targets. Then, a new enhanced hypotrochoid spiral optimization method (EHSOA) is developed to solve the complex co-optimization issue. An upgraded mechanism is initially introduced in this approach to prevent the optimization method from being caught in local optima. Compared with the original design, the suggested technique decreases initial mass by 5.08 percent, fuel usage by 26.10 percent, and battery deterioration by 2.0 percent. Eventually, it is proved that the suggested EHSOA is superior to existing optimization methods for solving the difficult co-optimization issue [143].

Yang et al. demonstrated a complete multi-objective optimization strategy for energy planning in local multi-energy frameworks with plug-in electric vehicles (PEVs), with the goal of enhancing the revenue of the companies in the local multi-energy frameworks while minimizing their CO_2 emissions. This subject concerns information exchange in local multi-energy infrastructure and determining optimal charge/discharge techniques for plug-in electric vehicles (PEVs) in order to optimize the profit while simultaneously reducing CO_2 emissions. It may be addressed by establishing a multi-purpose goal and a multi-objective programming problem by accurately describing the interdependencies involving power generation. Depending on the framework, a Modified Group Search Optimization (MGSO) method is employed to tackle this issue. The structural model dramatically improves local and global search. According to the outcomes of the potency test of the optimization method for maximizing the manufacturer's revenue while simultaneously lowering CO_2 emissions, this goal is attainable through optimized coordination of multiple power generation in local multi-energy structures and efficient implementation of the customization gathered on both the demand and supply sides [144].

Vasanth et al. have developed an enhanced version of the Wild Horse Optimizer called the Improved Wild Horse Optimizer with Deep Learning-enabled system for Battery Management (IWHODL-BMS). This approach is specifically designed for Internet of Things (IoT) based Hybrid Electric Vehicles (HEVs) and focuses on battery management. The IWHO method is used as a hyperparameter optimizer to improve the SOC estimate efficiency of the ABiGRU method. The implementation of the ABiGRU model leads to an easier and more precise portrayal of the input. A modeling and simulation result revealed the superior performance of the IWHODL-BMS model in comparison to alternative approaches, as measured by a variety of parameters [145].

11.2. Optimization Techniques for RES Integration to Grid

The research works on applications of optimization techniques for integrating RES to the grid are elaborated here.

Nayak et al. formulated an inherited competitive swarm optimization (ICSO) algorithm for the optimal placement and rescheduling of the battery energy storage systems in combination with the wind energy system. The formulation of the ICSO has been done based on human generation aging, in which the characteristics of the elder most on the generation is transmitted to their offspring. The algorithm proved to be better than the grasshopper algorithm [146].

Wang et al. developed a modified coot optimization algorithm (MCOA) for the optimal generation of the wind energy considering the various climatic changes. The MCOA has been based on the self-adaptive weighing technique which assist it to prevent from trapping in the region of the local optimal solutions. The penetration of the wind energy system and its operating cost has been significantly reduced with the application of the MCOA [147].

Xian and Che implemented Whale Optimization Algorithm (MWOA) with the association of support vector regression for the forecasting of the wind speed. They utilized the WOA to determine the optimal site and location of the wind energy system that would benefit the generation of power depending upon the intermittence of the wind speed [148].

Ullah et al. in their research developed a multi-objective wind driven optimization and multi-objective genetic algorithm to optimize the operation cost and the emission related to the power dispatch. The researchers also examined a combination of demand side management and incline block tariffs, which take the behavior of industrial and commercial customers into account [149].

Liu et al. analyzed the economic dispatch considering the thermal, wind, and solar energy system. In their work, they developed multi-objective moth flame optimization techniques to achieve the optimal performance of the economic dispatch model [150].

Rawa et al. developed an efficient optimization technique with the combination of the runga kutta and gradient optimizer to solve the transmission expansion planning. The planning for transmission was created by incorporating a wind and solar energy system, along with a battery energy storage system [151].

Krishnan and Kumar formulated a hybrid optimization approach based on the combination of Gurra fish optimization and isolation forest optimization for computing the optimal performance of the controller parameters for a microgrid. The complete microgrid framework is comprised of a solar photovoltaic system and a renewable energy system. The results achieved with the optimization technique have been superior in comparison to the optimization algorithms such as artificial bee colony optimization and ant lion optimization techniques [152].

Jiang et al. developed a demand response considering the economic operation of the microgrid with the influence of renewable energy sources. They utilized an improved wave optimization algorithm for their problem. The model WWO behavior is influenced by water waves. Waves prevailing on the ocean's surface contain complicated yet intriguing interactions that may be exploited to address optimization issues. In this method, every solution to a problem is symbolized as a water wave, which undergoes modifications in the search space as a result of three actions: propagation, refraction, and decay. This method is preferred because of its straightforward structure, elitism, and the ability to escape from local optima due to the presence of multiple search agents and the recombination of generations. Thermal and electrical dynamic load sharing and a thermal energy storage system led to a reduction in operating expenses, according to the findings [153].

11.3. Summary of Optimization Techniques for EV and RES Integration to Grid

The summarization and the research output ached with the various optimization techniques applied in the field of EV and RES by the research, which can be found in Table 7.

Table 7. Summarization and contribution of optimization techniques applied in the field of EV and RES.

Ref No.	Year	Topic	Implemented Optimization Techniques	Research Description
[140]	2022	EV	Differential Evolution Quantum Particle Swarm Optimization Algorithm (IDE-QPSO)	Taking inspiration from the Differential Evolution Algorithm, they have introduced the differential evolution operator to the iterative process of particle evolution, resulting in the creation of the IDE-QPSO algorithm
[141]	2022	EV	Augmented ε-constraint method and lexicographic optimization	A technique for effectively dealing with multi-objective HEMS (Home Energy Management Systems) problems is introduced, which involves combining the augmented ε-constraint method with lexicographic optimization
[142]	2022	EV	Convex optimization	Optimizing fuel economy in a PHEV involves a hybrid algorithm that integrates Convex Programming (CP) with real-time energy management strategies (EMSs) resulting in a CP-ECMS predictive EMS
[143]	2022	EV	Enhanced Hypotrochoid Spiral Optimization algorithm (EHSOA)	The first step in this algorithm involves proposing an improved bi-considering mechanism that prevents the optimization process from getting stuck in local optima
[144]	2022	EV	Modified Group Search Optimization (MGSO)	The suggested framework leads to a substantial enhancement in both local and global search
[145]	2022	EV	Improved Wild Horse Optimizer (IWHO)	The hyperparameter optimization process makes use of the IWHO algorithm

Table 7. *Cont.*

Ref No.	Year	Topic	Implemented Optimization Techniques	Research Description
[146]	2022	RES	Inherited Competitive Swarm Optimization (ICSO) Algorithm	Enhanced the coordination between the exploration and exploitation
[147]	2022	RES	Modified Coot Optimization Algorithm (MCOA)	The self-adaptive weighting technique and turbulent technique are employed in this method to avoid getting stuck in local optimization, ultimately enhancing the accuracy of predictions beyond what is achievable with the original Coot Optimization Algorithm (COA). The modified COA metaheuristic model, which employs these two techniques, displays a lower standard deviation when compared to other metaheuristic algorithms
[148]	2022	RES	Whale Optimization Algorithm (WOA)	Unified optimization and the WOA are used to solve the parameter selection problem. The global selection of parameters is achieved by the unified optimization, which considers the interactions between different models
[149]	2022	RES	Multi-Objective Wind-Driven Optimization (MOWDO) Algorithm and Multi-Objective Genetic Algorithm (MOGA)	Compared to existing models that involve or do not involve hybrid schemes, the energy optimization model improves the performance of a smart microgrid by minimizing its operational cost, lowering pollution emissions, and enhancing availability
[150]	2022	RES	Moth-Flame Optimization Algorithm (MFOA)	To address the high-dimensional, non-linear, and non-convex nature of the HDEED (High-Dimensional Expensive Optimization Problem with Expensive Constraints), a new optimization algorithm called MFO_PDU (Moth-Flame Optimization algorithm with Position Disturbance Updating strategy) has been introduced
[151]	2022	RES	Hybrid Runge Kutta Optimizer-Gradient-Based Optimizer (HRKOGBO)	Improved solution and avoidance of local optima.
[152]	2021	RES	Hybrid Garra Rufa Fish Optimization (GRFO)—Isolation Forest (Iforest)	The GRFO-iForest technique surpasses other methods in both steady-state and transient operation. It enhances the sustainability of the microgrid by restoring it to its normal operational status after minor physical disruptions and maintains stability by utilizing regulators in an optimized manner
[153]	2021	RES	Improved Water Wave Optimization Algorithm (IWWOA)	In this algorithm, each solution to a problem is depicted as a water wave, which undergoes modifications in the search space due to three behaviors: propagation, refraction, and decay of the waves or problem solutions

The integration of electric vehicles (EVs) into power systems is an active area of research, and there are several directions that researchers are currently pursuing to optimize the integration. Some of the research directions are:

- Optimal charging and discharging strategies: Researchers are investigating optimal charging and discharging strategies for EVs to minimize the cost of electricity and reduce the impact of EVs on the power grid. Optimization techniques, such as dynamic programming and model predictive control, are being used to find the optimal charging and discharging schedules.

- Vehicle-to-Grid (V2G) technology: V2G technology allows EVs to discharge their stored energy back into the grid, which can help balance the power supply and demand. Researchers are exploring the optimal scheduling of V2G systems to maximize the benefits to both the EV owners and the power system operators.
- Energy management systems: Energy management systems (EMSs) can control and optimize the charging and discharging of EVs in real-time based on the power grid's current state. Researchers are exploring the development of EMSs that can take into account factors such as the availability of renewable energy sources, grid congestion, and user preferences.
- Battery degradation: Battery degradation is a critical issue for EVs. Researchers are exploring optimization techniques to extend the life of EV batteries by minimizing battery usage, optimizing charging and discharging schedules, and managing battery temperature.
- Grid stability and security: The integration of EVs into the power grid can impact grid stability and security. Researchers are exploring optimization techniques to ensure that the power grid remains stable and secure with the increasing penetration of EVs.

The application of optimization techniques in renewable energy system integration in power system grid is a rapidly evolving research field. Some current research directions in this field are:

- Optimal power flow (OPF): OPF is an important optimization technique used to optimize the operation of power systems. Recent research has focused on developing new algorithms to solve the OPF problem in power systems with high levels of renewable energy penetration.
- Energy storage optimization: Energy storage systems (ESS) are increasingly being used in power systems to improve the integration of renewable energy sources. Research in this area is focused on developing algorithms to optimize the use of ESS to minimize system costs while ensuring the reliability of the power system.
- Demand response: Demand response (DR) programs allow consumers to adjust their energy consumption in response to changes in electricity prices or grid conditions. Research in this area is focused on developing algorithms to optimize the use of DR to minimize system costs and reduce the need for additional capacity.
- Renewable energy forecasting: Accurate forecasting of renewable energy production is critical for the effective integration of renewable energy into power systems. Research in this area is focused on developing improved forecasting models that can account for the variability and uncertainty of renewable energy sources.
- Distributed generation: Distributed generation (DG) refers to the generation of electricity from small-scale sources located close to consumers. Research in this area is focused on developing algorithms to optimize the use of DG to minimize system costs while ensuring the reliability of the power system.

Overall, the application of optimization techniques in EV integration is a promising area of research that can help to maximize the benefits of EVs while minimizing their impact on the power system grid. In addition to this, the application of optimization techniques in renewable energy system integration in power system grid is a dynamic and rapidly evolving research field, with a focus on improving the efficiency, reliability, and sustainability of power systems with high levels of renewable energy penetration.

12. Discussions

This review puts forward the latest research developments in the paradigm of EV and RES integration into the grid. A total of 153 documents, including reports, journal articles, and conference papers, are meticulously reviewed in this work. Quantitative analysis of EV and RES integration into power system grids typically involves modeling the power system and simulating different scenarios with varying levels of EV and RES penetration.

The integration of EVs and RES presents both challenges and opportunities for the power system grid. Some of the key parameters that are typically considered in the reported works include:

1. EV and RES penetration rates: Higher penetration rates can reduce greenhouse gas emissions and improve air quality, but they can also present challenges for the power system grid in terms of grid stability and reliability.
2. Charging patterns and RES generation variability: The timing and duration of EV charging can have a significant impact on the power system grid, and the variability of RES generation can also impact the ability of the grid to balance supply and demand. Managing the charging patterns of EVs and the variability of RES is key to ensuring grid stability and reliability.
3. Grid capacity and flexibility: The ability of the power system grid to handle increased demand from EV charging and renewable energy generation depends on the capacity of the grid as well as its flexibility to adapt to changing demand and generation patterns. This can include the availability of energy storage systems and the ability to manage variable generation from sources such as wind and solar.
4. Transmission and distribution infrastructure: The integration of EVs and RES often requires upgrades to the transmission and distribution infrastructure, including new transmission lines and substations.
5. Energy storage: Batteries can serve as a medium of storage and help to smooth out the variability of RES and provide grid stability during times of high demand.
6. Economic and regulatory factors: The cost of EVs and renewable energy technologies, government policies and incentives, and market design can all impact the adoption of EVs and RES in the power system grid.

Using these parameters, quantitative analysis can help identify the potential impact of EVs and RES integration on the power system grid and inform policy decisions related to infrastructure upgrades, energy storage deployment, and regulatory frameworks for EV and renewable energy adoption. The analysis can also help identify the most cost-effective ways to integrate EVs and renewable energy sources into the grid while maintaining grid stability and reliability.

13. Conclusions

Global warming, pollution, and the depletion of fossil fuels have forced mankind to delve into alternate sources of energy and cleaner modes of transport. In recent years, RES has been massively introduced to the grid. Also, EVs are becoming popular as a cleaner mode of transport. However, the introduction of RESs and EVs to the grid has imposed additional challenges on the grid operators because of their random nature. Unplanned placement of EV chargers and uncoordinated charging may cause serious issues such as degradation of the voltage profile and reliability indices, harmonic distortions, and power losses. Similarly, increased RES penetration on the grid may result in power quality issues.

This review focuses on the integration of RES and EVs to the grid and reports comprehensively on the global status of RESs and EVs, impact of integrating RESs and EVs to the grid, challenges of integrating RES and EV to the grid and the mitigation techniques, soft computing applications to EV and RES. It has been observed that soft computing techniques are predominantly applied for solving different optimization problems related to RES and EV.

Our future work will address:

- Planning and operation of energy system having EV and RES
- EV integrated Virtual Power Plant (VPP)
- Metaheuristics for planning and operation of smart power networks

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Abbreviations

AC	Alternating Current
DC	Direct Current
BEV	Battery powered electric vehicle
EV	Electric Vehicle
HEV	Hybrid Electric Vehicle
RES	Renewable Energy Source
TCO	Total cost of ownership
RSP	Risk Sharing Program
MDP	Markov Decision Program
ToU	Time of Use
V2G	Vehicle to grid
THD	Total Harmonic distortion
SAIFI	System Average Interruption Frequency Index
SAIDI	System Average Interruption Duration Index
CAIDI	Customer Average Interruption Duration Index
AENS	Average Energy Not Served
CSO	Chicken Swarm Optimization
SOCP	Second Order Cone programming
VRP	Voltage Stability Reliability Power Loss
VPP	Virtual Power Plant
UCP	Uncontrolled charging pattern
RCP	rapid charging pattern
SCP	smart charging pattern
POI	Point of Interest
CCT	Critical Clearance time
SDEWES	Water and Environmental Systems
VRT	voltage ride-through
GHG	Greenhouse gas
SSO	Single sign on
RES-ESS	Renewable Energy Sources-Energy Storage Systems
VRE	Variable Renewable energy
DV	Damaging Vibration
UFLS	under frequency load shedding
CFS	Energy Storage Cost
PAR	peak-to-average ratio
DI	Discomfort Index
HEMS	Home Energy management systems
EHSOA	hypotrochoid spiral optimization method
IWHODL-BMS	Improved Hild horse Optimizer with Deep learning-enabled system for battery management
ICSO	Inherited competitive swarm optimization
MCOA	Modified Coot Optimization Algorithm
MM-QR	Moment's Quantile Regression
MWOA	Modified Whale Optimization Algorithm

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