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Review

Integration of Renewable Energy and Electric Vehicles in Power Systems: A Review

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Abstract: Electric vehicles (EVs) represent a promising green technology for mitigating environmental impacts. However, their widespread adoption has significant implications for management, monitoring, and control of power systems. The integration of renewable energy sources (RESs), commonly referred to as green energy sources or alternative energy sources, into the network infrastructure is a sustainable and effective approach to addressing these matters. This paper provides a comprehensive review of the integration of RESs and EVs into power systems. The bibliographic analysis revealed that IEEE Access had the highest impact among journals. In order to enhance the classification of the reviewed literature, we have provided an analytical summary of the contributions made by each paper. The categorization facilitated the recognition of the primary objectives explored in the reviewed works, including the classification of EVs and RESs, the incorporation of RESs and EVs into power systems with an emphasis on emissions, the establishment of EV charging stations and parking facilities, EV batteries and battery energy storage systems, strategies for managing the integration of RESs with EVs, EV aggregators, and the financial implications. In order to provide researchers with a valuable synopsis of the implementation particulars, the papers were bifurcated into two primary classifications, namely mathematical algorithms and heuristic algorithms. The mixed integer linear programming algorithm and particle swarm optimization algorithm were commonly utilized formulations in optimization. MATLAB/Simulink was the primary platform used for executing a considerable portion of these algorithms, with CPLEX being the dominant optimization tool. Finally, this study offers avenues for further discourse and investigation regarding areas of research that remain unexplored.

Keywords: electric vehicle; literature review; renewable energy sources; power systems

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1. Introduction

The efficient use of energy has significantly contributed to the advancement of civilization. During the pre-industrial epoch, the predominant sources of energy were derived from human and animal labor, as well as the combustion of wood for the purposes of cooking, heating, and metal smelting. The utilization of coal played a pivotal role in the onset of the industrial revolution, as it facilitated the mechanization of various industries, improved transportation systems, and propelled the emerging technology of steam engines. During the preceding century, the exploration and utilization of fossil fuels constituted a significant catalyst for economic growth and advancement [1].

However, the utilization of fossil fuels such as natural gas, oil, and coal incurs substantial expenses related to climate change, ecological degradation, and public health that are not accounted for in prevailing market valuations. The aforementioned costs are commonly referred to as externalities within academic discourse. Externalities are generated at every stage of the supply chain of fossil fuels, including combustion, refining, transportation, and extraction. The process of combusting fossil fuels results in the release of carbon dioxide (CO_2) into the atmosphere. This phenomenon is considered to be the primary contributor to the current climate change, which is causing alterations in the Earth's ecosystems and posing health risks to both the environment and human populations.

The accumulation of carbon in storage amplifies the greenhouse effect, resulting in the phenomenon of global warming. In addition, aside from carbon dioxide, the combustion of fossil fuels results in the emission of nitrogen oxides and sulfur oxides, which contribute to the formation of acidic precipitation.

In recent decades, researchers have directed their attention towards alternative solutions for electricity production in order to mitigate the greenhouse effect and meet the growing demand for electricity. The aforementioned solutions rely on the premise that a majority of renewable energy sources can be readily transformed into electrical energy. The growth of renewable energy is currently experiencing a rapid expansion. Wind power and solar photovoltaic (PV) are widely adopted renewable energy sources. As of 2021, the grid-connected photovoltaic (PV) system has demonstrated remarkable growth and is currently considered the most rapidly expanding renewable energy technology, boasting a total capacity of 843.09 GW [2]. Meanwhile, wind power has also played a significant role in the renewable energy landscape thus far.

2. Related Work

Given the prevailing circumstances and with the aim of further reducing emissions, various novel technologies have been integrated into power systems. The integration of renewable and environmentally sustainable energy sources is essential in attaining carbon neutrality while simultaneously guaranteeing a consistent and cost-effective energy supply. The ongoing shift towards a sustainable and eco-friendly energy system necessitates expediting the process and revolutionizing pivotal industries such as transportation while simultaneously establishing the requisite infrastructure and governance [3]. Electric vehicles are a technology that is increasingly gaining popularity thanks to their environmentally sustainable nature. According to a recent study, it is projected that the revenue generated from the electric vehicle market will reach a value of $457.60 billion by the year 2023. Additionally, the study estimates that the sales volume of electric vehicles will reach 16.21 million units by the year 2027 [4].

Enhancing the energy efficiency of vehicles, specifically in terms of energy consumption per unit distance, is a significant constraint in augmenting the levels of greenhouse gas emissions from road transportation. The enhancement of vehicle efficiency can be attained through the advancement of novel vehicle technologies and the augmentation of pre-existing technologies [5], while the work of [6] conducts a comprehensive evaluation of contemporary energy storage systems intended for use in automotive contexts. The literature has extensively analyzed the fundamentals, theory, and design of EVs [7–11].

3. Contribution

This manuscript provides a comprehensive analysis of the incorporation of sustainable energy sources and electric automobiles into electrical grids. The assessment encompasses a total of 175 pieces of literature that have been published within the last 15 years. The primary contributions can be summarized as follows:

1. To the best of the authors' knowledge, this is the first comprehensive review of the amalgamation of renewable energy technology within power grids, coupled with electrification applications.
2. The publications were arranged in chronological order to highlight the research focus of the last fifteen years. This enables researchers to ascertain whether additional inquiry is justified.

3. The estimation of the impact of highly influential journals is determined by the aggregate number of publications attributed to each respective journal. This information enables researchers to determine the frequency of publication in a given journal, thereby aiding in the selection of an appropriate venue for disseminating their research findings.
4. The analytical presentation of each work's contribution in a table facilitates the researchers' comprehension of the topic and enables them to acquire a general understanding of it efficiently.
5. A taxonomy of integration objectives pertaining to renewable energy sources and electric vehicles is carried out.
6. The analysis of relevant literature led to the extraction of conclusions pertaining to the algorithms utilized and their specific implementation details.
7. The identification of gaps in the existing literature has led to the highlighting of potential areas for future research.

The subsequent sections of the document are structured in the following manner. Section 4 provides an overview of the background of RES, whereas Section 5 offers an account of the background of EV. Section 6 presents a bibliographic analysis of the 175 works that were reviewed. Section 7 outlines the primary contribution of each publication, while Section 8 offers a discourse on the integration objectives of RESs and EVs. Section 9 outlines the algorithms utilized and various implementation details. Section 10 of the paper addresses potential areas for future research, while Section 11 provides concluding remarks.

4. Renewable Energy Sources

A power system is a complex system of components that converts the conventional energy from coal as well as the energy provided by renewable energy sources into electrical energy [12]. The term *renewable energy sources* refers to energy sources derived from resources that can be renewed naturally on a human timeline. Wind, solar PV, hydropower, natural gas, and bioenergy all qualify as examples of renewable sources. Renewable energy is frequently utilized for the generation of electricity, as well as for heating, cooling, and transportation.

Considering the proportion of total power capacity based on the different types of energy sources, the wind and solar PV penetration was incremental in the last decade, as is the estimation for the coming years [13]. These two renewable energy sources are the dominant renewables considering their integration along with EVs.

4.1. Wind Energy

Effective wind farm installation, based on an optimal arrangement of wind turbines (WTs), maximizes electricity generation. Wind speed influences wind energy [14]. Wind speed may be measured below wind turbines using testing equipment. The 1/7 power law is utilized to estimate the wind speed at a specific height for a turbine's wind profile [15]:

$$\left(\frac{v}{v_r}\right) = \left(\frac{h}{h_r}\right)^c \tag{1}$$

The formula for calculating wind speed at a certain height v involves the known wind speed at a different height v_r, a coefficient c, and the height at which the wind speed is being measured h. The coefficient typically ranges between 0.1 and 0.4.

Meteorological factors such as wind speed and air density have a significant impact on the amount of electricity produced by wind energy, as demonstrated by [16]:

$$P = \frac{1}{2} a \rho A V^3 \tag{2}$$

In the above equation, V represents wind speed expressed in m/s, A is the swept area of the wind turbine in m^2, ρ denotes the density of air in kg/m^3, and α represents the Betz's constant.

4.2. Solar Energy

Photovoltaic (PV) solar panels or concentrated solar power plants may transform solar energy into electricity. Although PV solar panels employ solid-state semiconductors to convert sunlight directly into electricity, concentrated solar power plants utilize lenses or mirrors to focus solar radiation, producing enough heat to power steam turbines or engines to generate energy [17].

PV solar panels use solar cells, which function well at low temperatures. As the temperature rises, solar cell power efficiency, n_{solar}, remains constant. The electricity output, P_{solar}, can be calculated considering the solar irradiation intensity, s, expressed in W/m^2, and the area of aggregated solar cells, α, expressed in m^2.

$$P_{solar} = n_{solar} s \alpha \tag{3}$$

The electricity generated by photovoltaic solar panels can be expressed as follows:

$$P_{PV} = A\beta\mu(t) \tag{4}$$

where A represents the panel's area, β represents its efficiency, and μ represents the solar insolation whose value can be selected based on official statistics.

5. Electric Vehicles

A mode of transportation powered by electricity is referred to as an electric vehicle. Electric vehicles are not a new concept, with experts investigating them since the 19th century. EVs have been studied by a vast number of researchers and engineers, and their progress has always been influenced by economic and environmental factors. Some of the most significant events that have had an impact on the development of electric vehicles are mentioned bellow [18].

- 1832: Robert Anderson created the first primitive EV.
- 1901: Edison tackles the issue of EV batteries; Ferdinand Porsche created the first hybrid EV.
- 1968: Oil crises lead to a resurgent interest in EVs.
- 1971: NASA's lunar rover was the first electric vehicle utilized for Moon exploration.
- 1974: Many companies started to design and produce EVs.
- 1990: New regulation for electromobility.
- 1997: Toyota Prius was the first mass-produced hybrid EV.
- 2010: Nissan Leaf was the first mass-produced full electric EV; Chevy Volt was the first mass-produced plug-in hybrid EV.
- 2013: Cost reduction for EV batteries.
- 2014: Massive production of EVs from different companies.
- 2022: Global sales of electric vehicles increased by about 60%, surpassing 10 million for the first time.

There are three distinct categories of electric vehicles now available on the market [19]:

- Vehicles using a gasoline engine and an electric motor are called *hybrid electric vehicles*. While the car is moving slowly or at a complete stop, such as in traffic, the electric motor assists with propulsion.
- Similar to hybrid electric vehicles, but with the added convenience of being able to plug in and charge from an electrical outlet, *plug-in hybrid electric vehicles* offer the best of both worlds.
- Vehicles using electric motors and batteries as power sources are known as *full electric vehicles*.

In recent times, a novel classification, namely the *fuel cell electric vehicle*, has been incorporated. A fuel cell EV is capable of producing its own electrical power through the use of hydrogen fuel cells, in contrast to conventional EVs that exclusively rely on batteries. It is noteworthy that there exist 60 electric vehicle (EV) manufacturing companies globally, with 43 of them having already introduced their models into the EV market. Table 1 displays the top five companies in terms of sales of plug-in hybrid and full electric vehicles in the year 2022. According to the source [20], BYD held a significant market share of 18.4% in the plug-in hybrid electric vehicle sector, whereas Tesla emerged as the dominant company with an 18.2% share in the global market.

Table 1. The top five corporations with the highest sales of plug-in hybrid and full electric vehicles in the year 2022.

Plug-In Hybrid Electric Vehicles		Full Electric Vehicles	
EV Company	**EV Sales**	**EV Company**	**EV Sales**
BYD	1,857,549	Tesla	1,314,330
Tesla	1,314,330	BYD	913,052
Volkswagen	831,844	SAIC	671,725
SAIC	724,911	Volkswagen	571,067
Geely-Volvo	606,114	Geely-Volvo	383,936

6. Bibliographic Analysis

To conduct a bibliographic analysis on the integration of renewable energy sources and electric vehicles into power systems, data from 175 sources were collected from various digital libraries, including IEEE Xplore, as referenced in the works [21–195]. The downloaded information regarding metadata comprises various details such as the publication date, title, abstract, authorship, references, and keywords. Additionally, it includes information on implementation, computational environment, and citations.

6.1. Chronological Distribution Analysis of Research Works

In the context of this analysis, the year of publication of the reviewed works was taken into consideration. Figure 1 illustrates the temporal distribution of the published works within the period spanning from 2009 to the present day.

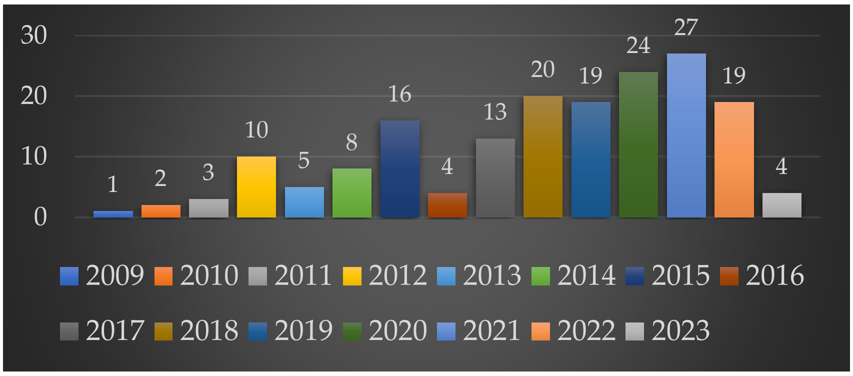

Figure 1. Chronological distribution of the published works.

The results indicate that the incorporation of renewable energy sources and electric vehicles into power systems has garnered considerable attention from scholars over the past half-decade.

6.2. Citations and Impact of Works in Terms of Publications Per Journal

As of February 2023, a total of 175 works have been cited 15,428 times. Table 2 displays the top five most frequently referenced publications within the literature. It is noteworthy that the aforementioned works have garnered over 350 citations, with the latest publication dating back to 2014.

Table 2. The five most cited works in the literature.

n/n	Reference	Year	Citations
1	[79]	2014	1003
2	[78]	2013	970
3	[160]	2011	927
4	[132]	2012	424
5	[165]	2012	369

Table 3 displays the journals that have published more than three articles and are considered the most "productive" based on the number of publications.

The percentage distribution for the total of 175 journal articles is illustrated in Figure 2.

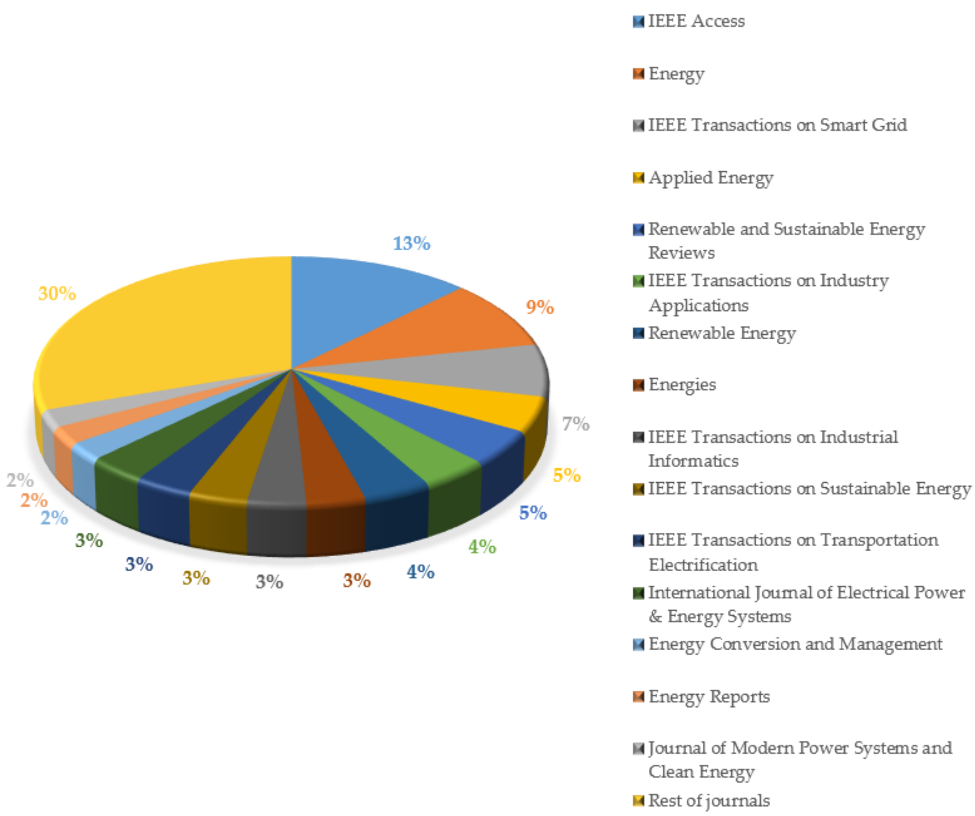

Figure 2. Impact of journal articles in terms of publications per journal.

Table 3. Most "productive" journals in terms of publications.

n/n	Journal Title	Publications
1	IEEE Access	22
2	Energy	16
3	IEEE Transactions on Smart Grid	12
4	Applied Energy	8
4	Renewable and Sustainable Energy Reviews	8
6	IEEE Transactions on Industry Applications	7
6	Renewable Energy	7
8	Energies	6
8	IEEE Transactions on Industrial Informatics	6
8	IEEE Transactions on Sustainable Energy	6

Table 3. *Cont.*

n/n	Journal Title	Publications
8	IEEE Transactions on Transportation Electrification	6
8	International Journal of Electrical Power & Energy Systems	6
13	Energy Conversion and Management	4
13	Energy Reports	4
13	Journal of Modern Power Systems and Clean Energy	4

7. Contributions of the Published Works

Table 4 presents the individual contributions of the 175 publications that were reviewed.

Table 4. Contributions of reviewed works.

Reference	Contribution
[21]	Study of EV and PV production considering vehicle-to-grid techniques, uncontrolled charging, and smart charging.
[22]	Implementation of solar PV and WT systems for the development of eco-friendly EV charging stations.
[23]	Optimal integration of battery energy storage systems, WTs, and PVs in distribution systems considering the increase in demand due to the existence of EV charging stations.
[24]	An RES and EV microgrid scheduling proposal based on empirical restrictions, errors related to renewable power forecasting, spinning reservation, and EV owners' delight.
[25]	Implementation of flexible transmission technology for optimally integrating plug-in EVs and RESs.
[26]	Proposal of a fully sustainable and profitable power system incorporating PVs, WTs, fuel cell EVs, and hydrogen.
[27]	An analysis of the effects of widespread deployment of different type EVs in Northern Europe's power systems.
[28]	Techno-economic feasibility analysis of incorporating PV systems into fuel stations for EV charging.
[29]	The impact of EV charging strategies on wind energy production and utilization in Danish energy systems.
[30]	Balancing of intermittent RESs in the presence of plug-in EVs.
[31]	Development of graphene nano battery for EVs.
[32]	A review of EV battery design models and energy systems.
[33]	A unit commitment model that incorporates energy demand, EVs, and wind generation and optimizes the scheduling of power demands during periods of high wind generation.
[34]	Regulation of EV charging loads and mitigation of rapid fluctuations in distributed RESs through power smoothing or ramp rate limitation.
[35]	A smart grid reconfiguration method considering uncertainty in wind energy and EV penetration to maximize system flexibility and lower predicted operational costs.
[36]	Optimization of fast-charging station installation and operation in light of EV demand and the existence of RESs.
[37]	An optimization method for optimal placement of PVs, WTs, and capacitor banks in power systems considering plug-in EV load demand.
[38]	A plug-in EV coordination control technique for improving frequency stability and preserving micro-grid dynamic considering RESs as well.
[39]	Optimization frameworks for a movie theater complex's plug-in hybrid EV parking lot's power supply, location, and time-variable charge distribution.
[40]	A hybrid unit commitment framework considering several cases including renewables and demand side management for dispatchable plug-in EV loads.
[41]	A complete strategy for addressing the approaching electrification issues in emergent nations.
[42]	An optimal unit commitment scheduling linked with solar and wind energy as well as EVs, minimizing the power system's economic cost, including unit operating expenses and electric vehicle charging and discharging costs.

Table 4. *Cont.*

Reference	Contribution
[43]	A business model for speeding up the integration of EVs in terms of an intelligent rechargeable network.
[44]	The interactions between plug-in hybrid EVs, wind generation, and demand response are studied through a unit commitment model.
[45]	Calculation of the feasibility of incorporating EVs into the Inner Mongolian energy system in order to exploit the wind potential.
[46]	A capacity expansion model to identify the lowest-cost combination of additional power plants and regulated auto charging to meet several aspects such as EV availability, operating limitations, and so on.
[47]	Assessment of EV fleets' potential using variable RESs for charging and minimizing conventional generation.
[48]	A formulation that simulates modes of charging that are intermediate.
[49]	An efficient power plant model that takes into account EVs' temporal traveling behaviors using a virtual power plant based on EV aggregation, as it supports power system operation with maximum and lowest generating outputs.
[50]	A multiobjective expansion planning framework that maximizes charging station utilization and reduces investment net present value.
[51]	An EV-responsive variable renewable energy curtailment method to reduce energy waste and economic losses.
[52]	An investment model combining power and heat generation and production of EVs and WTs.
[53]	A forecast of the power generation potential of WTs and plug-in hybrid EVs in Northeast Brazil.
[54]	The charging and discharging of EVs at night and how this affects the amount of wind power is studied.
[55]	Analysis of the potential synergistic effects of EV charging, solar, and wind in Portugal.
[56]	Analysis of EV charging costs utilizing RESs in Canada.
[57]	Integration of PVs and EV smart charging to establish the minimal penetration levels needed to meet climate and energy targets.
[58]	Power distribution network implications of charging or discharging plug-in hybrid EVs and/or EVs as well as distributed generators using renewable energy.
[59]	A two-stage model incorporating stochastic processes for plug-in EV charging and integration of RESs.
[60]	An adaptive intelligent controller to handle energy demand inconsistencies and generation source intermittency to integrate RESs and EVs.
[61]	A decentralized model for EV integration and considering environmental conditions.
[62]	Evaluation of EV integration into the Italian power network and its synergy with renewable energy electricity generation, including CO_2 emissions, costs, and medium-to-long-term curtailments.
[63]	Analysis of the EVs' impact on a small isolated power supply, specifically in terms of their static additional demand or as vehicles with vehicle-to-grid (V2G) services and smart charging.
[64]	A smart charging technique that addresses renewable energy resource critical effects and supports EV energy demand, enhancing grid dependability, and power quality.
[65]	Minimization of the daily gas and power costs for a multi-energy system structure considering residential and commercial endusers, operational flexibility, and EVs as a new type of electrical demand.
[66]	A multi-objective approach to optimize the sizing of a microgrid with electric vehicles in two modes, while accounting for their unpredictable behavior.
[67]	An examination of how plug-in electric vehicles' integration intelligence influences the energy storage system capacity to satisfy the objectives of RESs in California.
[68]	A technique that assists utilities in managing energy consumption in microgrids with EV fleets, while a small residential, solar-powered building model schedules daily household load using home demand-side management based on three appliance categories and EV battery energy storage systems.
[69]	Examination of microgrid operation involving EVs and RESs through a multi-layer energy management system that incorporates real-time and day-ahead electricity markets.

Table 4. *Cont.*

Reference	Contribution
[70]	Municipal energy system design using flexible-possibilistic stochastic programming to minimize cost and emissions.
[71]	Design of a station capable of simultaneously recharging and refilling fuel cell and battery EVs in Sub-Saharan Africa.
[72]	Two different dispatch techniques considering V2G technology and PV generation for Florianópolis' urban area in Brazil.
[73]	An optimization model considering RESs and EV operating patterns.
[74]	Optimal scheduling of EVs that have the capability to deliver energy in both directions while accounting for various uncertainties.
[75]	A cooperative game framework that employs Nash bargaining to facilitate trading of energy among incorporated power systems and charging facilities for EVs.
[76]	Optimization of the charging of EVs to mitigate the variability of RESs.
[77]	Proposal of a hybrid RES system configuration for EV charging stations, considering economical, environmental, and technical aspects.
[78]	A review of RESs' integration considering EVs' economical, environmental and technical consequences.
[79]	A literature review on RESs' integration and the possible solutions employing EVs along with smart V2G system viability.
[80]	A review of the interaction between EVs and RESs in smart grids.
[81]	A review of future energy options for EV charging mechanisms and a plan to cut greenhouse gas emissions by automatically recharging EV battery banks with wind and solar power.
[82]	A survey of hybrid EVs and renewable energy systems considering multiple input DC–DC converter topologies.
[83]	A stochastic programming framework for scheduling a grid-connected microgrid in advance including wind turbines, solar units, microturbines, fuel cells, and two fleets of plug-in EVs.
[84]	A financial emissions dispatch model that incorporates plug-in EVs and WTs.
[85]	Power quality analysis of fuel cell generation units, solar panels, and WTs with high EV charging station penetration.
[86]	A Bass diffusion model to estimate any future diffusion considering the integration of solar panels and EVs utilizing historic information obtained from the Netherlands.
[87]	Analysis and design of hybrid power networks for the utility and transportation needs of a single-family building.
[88]	Evaluation of power system flexibility and scheduling flexible resources incorporating renewable energy and EVs using an improved particle swarm optimization (PSO) technique.
[89]	A management system model for a household equipped with adjustable electric loads, an EV, and a microgrid powered by wind and PV generation, along with battery storage.
[90]	Optimizing renewable power networks in supermarkets alongside EV charging stations.
[91]	A scheduling and pricing technique for plug-in EVs' charging/discharging to synchronize and track with power generation of renewable sources.
[92]	An online optimal mixed integer linear programming control technique for managing microgrids that incorporate RESs, EVs, and battery storage.
[93]	A tripartite collaborative decision-making procedure enabling the virtual energy hub to participate in the electricity market as a business entity.
[94]	EV aggregators' best bidding techniques with fluctuating wind generation.
[95]	A frequency regulation approach for a hybrid power system comprising EVs and hybrid renewable generation in a deregulated environment.
[96]	Optimization of EVs' charging dispatch and account for renewable energy and load demand multiuncertainties.
[97]	Adaptive, dynamic, wireless EV charging system that utilizes wind energy and power grid electricity to meet charging demand while reducing power grid peak demand pressure and carbon emissions.

Table 4. *Cont.*

Reference	Contribution
[98]	This study aims to optimize the utilization of EVs as devices for storing energy for a sustainable power network, with the goal of reducing emissions.
[99]	Study of power network reliability issues relating to electric vehicles and solar and wind energy.
[100]	A two-stage management model for plug-in EV parking lots, taking into account the size and placement of PV panels and WTs.
[101]	A hybrid solar and wind generation probabilistic model to address extensive EV charging demands.
[102]	An optimization strategy for microgrids that incorporates RESs and EVs to facilitate demand response programs.
[103]	A DC microgrid connecting the EV charging stations to intermittent solar and wind power energy sources on a separate network from the United Kingdom's main power grid.
[104]	Application of Kalman filter for liquid hydrogen station in vehicles.
[105]	Analysis of parameters of a load frequency controler.
[106]	A Q-iteration algorithm for reinforcement learning to coordinate the charging of EVs as a sequential decision-making approach, reducing renewable power curtailment and enhancing system flexibility.
[107]	A scheduling technique for vehicle-to-grid systems that addresses the challenges posed by renewable energy volatility and battery protection.
[108]	Plug-in EV charging station design optimization using a bilevel approach.
[109]	A prioritization ranking algorithm and blockchain-based EV incentive system to maximize renewable energy use.
[110]	AMPL and CPLEX were utilized to develop an aggregation method for optimizing a green energy index (GEI) in an EV charging coordination setting at a workplace. It investigates the interactions of building-integrated photovoltaics (BIPVs).
[111]	A bilevel energy management system for power grids that extensively incorporates RESs and EVs.
[112]	A gradient boosting regression tree method to estimate the level of charge of plug-in EV batteries in a solar powered charging-cum-parking lot.
[113]	A Markov decision process (MDP) optimal scheduling solution for EV charging stations powered by RESs in order to reduce waiting time.
[114]	A particle-swarm-algorithm-based adaptive control method for the coordinated control of wind farms, photovoltaic power, and EVs in a microgrid in terms of its frequency regulation.
[115]	A coordination technique for primary frequency management in a system that includes hydro-generation units and EVs.
[116]	A coordinated planning model for expanding EV charging infrastructure and renewables utilizing model predictive control (MPC) learning and the CVX optimizer.
[117]	A hybrid EV–wind power stochastic scheduling model for power systems to study pollution emission, wind power curtailment, and generation cost.
[118]	A two-stage optimum planning framework for a community power system that integrates EV charging stations, demand response, and dynamic pricing.
[119]	A study of the coordination challenges associated with charging EVs using wind generation in a group of buildings.
[120]	A dynamic energy consumption control approach that utilizes the frequency deviation signal to synchronize the different discharging/charging phases of EVs while accounting for periodic RESs' generation.
[121]	An efficient management method of RESs, EVs, and thermal units to establish a sustainable and intelligent power grid.
[122]	A charging management system for EVs based on a greedy-based auction method to mitigate photovoltaic curtailment caused by voltage spike in the distribution system.
[123]	Investigation of the price rivalry between RESs' generation with EV charging stations in a smart grid context by modeling their competitive price adjustment through game theory and maximizing their own payoff with a best response algorithm to prove supermodularity convergence.

Table 4. *Cont.*

Reference	Contribution
[124]	A decomposition of wavelet packets is used to determine supercapacitor power, grid-connected wind, and EVs. A knapsack problem examines the EV fleet's energy management demands, while dynamic programming optimizes EV and wind dispatch.
[125]	A review about EV owners' chances and obstacles to establish a home-based system that utilizes micro RESs to power vehicles.
[126]	A three-port integrated topology (TPIT) connects EVs and solar panels to the electrical grid, minimizing conversion steps and allowing novel operation modes and control algorithms without compromising power quality.
[127]	A three-level DC–DC converter equipped with dual inputs for fuel cell EVs featuring a hybrid power preservation network.
[128]	Optimal renewables' minimization in a store complex power system with a hybrid PV–WT microgrid and backup EV charging station.
[129]	Frequency regulation methods for a microgrid that is isolated featuring electric vehicles and a power preserving system.
[130]	A summary of the most recent trends and advancements in energy storage, renewable energy, electric vehicles, magnetic buses, and superconductors for future power grids.
[131]	A frequency control approach that is hierarchically adaptive for a smart grid integrated with electric vehicles and that can accommodate changes in load and wind generation.
[132]	A model for unit commitment that incorporates stochastic security restrictions and requirements related to power systems and plug-in EVs.
[133]	A management system utilizing multiple agents for balancing of demand and supply with high renewable energy and EVs and maximum participant profit within voltage control constraints.
[134]	A stochastic optimization algorithm for microgrid scheduling that considers several energy sources and EV charging in parking lots.
[135]	Prediction model for CO_2 emissions and industry cost in a power system integrating EVs and solar power.
[136]	A mathematical model to incorporate investment decisions into current aspects like EV and energy storage systems, which may affect future distribution network planning and expansion.
[137]	A control method implemented on a system consisting of a solar array, storage battery, grid, an EV charging station, and a diesel-powered generator.
[138]	This study examines the impact of plug-in EVs and wind farms on security-restricted generation unit commitment.
[139]	Optimization model of smart-meter-equipped EV aggregators in distribution systems.
[140]	Mathematical modelling of intelligent charging and vehicle-to-grid operation in distribution grids.
[141]	An intelligent EV charging management solution for transportation system charging stations decreasing the power grid's negative effects from charging EV fleets in electromobility. Both games' Nash equilibria were solved online.
[142]	RESs' and EVs' integration control and management of the generation–demand imbalances.
[143]	A security analysis of EV charging stations that utilize wind generation that considers charging frequency.
[144]	Implementation of a DC charger for EVs into a photovoltaic power infrastructure.
[145]	An aggregator for managing the energy profiles of photovoltaic power and EVs using a convex quadratic programming model and a robust multi-time scale energy management method.
[146]	An optimization model for emission dispatch that incorporates EVs and RESs as variables.
[147]	A combination of a net present value technique, a dynamic model, and a logit regression model demonstrates that incentive policies to accelerate plug-in EVs' deployment or DC charging station expansion affect wind capacity investment in the energy market, and vice versa.
[148]	Operational planning of EVs in a microgrid to balance fluctuations in wind power and demand.
[149]	This study addresses the optimal planning problem of a fully sustainable EV charging station, which relies exclusively on solar panels for its energy supply.
[150]	Optimal designing and execution of power networks integrating RESs and hydrogen fuel cell vehicles.

Table 4. *Cont.*

Reference	Contribution
[151]	A robust optimal week-ahead generation scheduling methodology considering renewable energy resources, plug-in hybrid EV behavior, and load unpredictability, as well as two heuristic-based algorithms, the gravitational search algorithm and the water cycle algorithm.
[152]	Determination of the most effective energy trading strategy for the microgrid of a building that incorporates storage units, EVs, and RESs.
[153]	An optimal approach for enhancing the stochastic performance of a power system that incorporates RESs and hydrogen vehicles.
[154]	An optimal two-level transactive energy trading framework for EV charging stations with solar panels.
[155]	This study proposes a method for balancing the residential consumption and production in a home equipped with photovoltaic and wind generation, EVs, and storage units.
[156]	An algorithm designed to manage solar farms and EV charging stations.
[157]	An EV and load frequency controller designed for interconnected electricity networks.
[158]	A two-step method addressing the planning problem of a charging EV station fueled solely by renewable energy sources based on risk theory, while MILP and LP reformulations affect the model precision and the computational tractability.
[159]	Replacement of the internal combustion engine of a plug-in hybrid EV with a compact rooftop solar module and a small front-mounted wind turbine.
[160]	A method for optimizing costs and reducing emissions by considering both plug-in vehicles and renewable energy sources.
[161]	A social coordinator's second-order cone program (SOCP) model for routing of plug-in EVs to explicitly describe either plug-in EVs' driving range or power grid electrical constraints.
[162]	A probabilistic AC–DC load flow method for efficient reactive power management in the presence of EVs, photovoltaic uncertainties, and offshore or onshore wind power.
[163]	A two-stage stochastic programming solution for power systems including RESs and plug-in EVs.
[164]	A flexibility evaluation method for power systems integrating EVs and RESs using a dichotomous embedded social learning algorithm.
[165]	This study examines the scheduling of smart grid resources while accounting for plug-in EVs and the uncertainty associated with RESs.
[166]	A model for optimizing under-frequency load shedding requirements that accounts for uncertainties in wind power and the randomness of EVs' commuting patterns.
[167]	A control system for superconducting magnetic energy storage that can be utilized in distribution grids incorporating EVs and RESs.
[168]	An optimal distribution feeder reconfiguration method for smart grids with plug-in EVs and WTs.
[169]	A deep reinforcement learning algorithm is used to develop a technique for large-scale EVs to absorb abandoned renewable energy electricity.
[170]	Analysis of the effects of multiple EV integration/control methodologies on utility grid performance considering the stochastic characteristics of residential loads and wind power output based on practical daily loading patterns.
[171]	A hybrid WT and PV system that also employs EVs and thermocompressors as regulated loads for extra load frequency control (LFC).
[172]	Flexible wireless charging system architecture, design, and optimization for renewable-energy-powered electric bicycles.
[173]	Technical concerns for EV and plug-in hybrid EV battery charging considering solar installations.
[174]	A techno-economic examination of China's fuel cell vehicle system, hydrogen production, and wind curtailment.
[175]	Transactive energy for combined EVs to lower peak system load taking into account network constraints.
[176]	Modeling and control architecture for efficient tracking of renewable electricity with plug-in EVs.

Table 4. *Cont.*

Reference	Contribution
[177]	A two-stage EV charging system that decides on the generated energy of the following day, at every time, dynamically.
[178]	This study explores the potential benefits of using a vehicle-to-home system to increase self-consumption of a domestic consumer who has a solar-powered roof.
[179]	An analysis of research pertaining to EV charging stations that use renewable energy sources.
[180]	Impacts of EV fleet types and charging options on emissions under variable wind power penetrations using an integrated energy system optimization model (IESOM).
[181]	Solar energy system optimization for EVs on the University Campus in Dhaka, Bangladesh, utilizing the HOMER software.
[182]	The operation of a distribution system that includes charging schedules for EVs and RESs.
[183]	EV batteries' charging in Romania using solar generation.
[184]	An Italian case assessment of the degree to which power storage can support EVs and achieve high levels of renewable energy integration by utilizing excess renewable energy that would otherwise be curtailed, quantifying the associated costs based on EnergyPLAN software.
[185]	Managing and control of a DC microgrid EV charging station utilizing solar PV arrays and WTs.
[186]	A techno-economic analysis of hybrid RES systems optimized for EV charging in the United Arab Emirates.
[187]	EVs' utilization for auxiliary thermal power's peak load management.
[188]	A charging approach for EVs to reduce the volatility of RESs.
[189]	An investigation on the effects that EVs' batteries have on the incorporation of RESs into the European grid by 2030.
[190]	The influence of EVs on Germany's prospective renewable energy infrastructure.
[191]	This study focuses on sizing a hybrid renewable energy system with multiple objectives, including power sharing and EVs.
[192]	An optimization strategy to balance renewable generation and fluctuating EV charging demand.
[193]	Integration of RESs and EVs into the Dubrovnik region's electricity network.
[194]	This study involves the development and evaluation of a hybrid renewable generation grid with storage units to satisfy EV charging.
[195]	Usage of EVs and RES as an emotional controller for load frequency management in deregulated systems.

The most important present objectives from all of the studies that were evaluated and took into account the current goals of combining RES and EVs are presented in Table 5. These objectives include the type of electric vehicles, the type of renewable energy sources, the integration of RESs and EVs into power systems targeting emissions, the electric vehicle charging stations and parking lots, the electric vehicle batteries and the battery energy storage systems, the control approaches for EVs to integrate RESs, the electric vehicle aggregators, and the cost impact. Furthermore, subsequent research ought to concentrate on examining power systems' demand, charging infrastructure capacity, smart energy management systems, integration of renewable energy sources, power system resiliency and adaptability, wireless charging, and the environmental impact of renewable energy sources. The upcoming sections will provide an analytical discussion of the current objectives and future works.

Table 5. Present objectives of reviewed works and research gaps for future work.

Present research objectives of reviewed works	Type of EVs
	Type of RES
	Integration of RESs and EVs into power systems targeting emissions
	EV charging station—EV parking lot
	EV batteries and battery energy storage systems
	Control approaches for EVs to integrate RESs
	EV aggregator
	Cost impact
Research gaps for future work	Power systems demand
	Insufficient capacity of the charging infrastructure
	Smart energy management systems
	Integration of other RESs
	Resiliency and adaptability of power systems
	Wireless charging
	Environmental impact of RESs' integration

8. RESs' and EVs' Integration Objectives

This section presents and discusses the main findings of all of the reviewed works considering RESs' and EVs' integration objectives.

8.1. Type of EVs

The literature contains reviewed works that can be categorized according to EV type, as outlined in Table 6. The findings indicate that the investigation pertaining to the amalgamation of RES and EVs in power systems predominantly concentrates on *full electric EVs*, with a limited amount of research directed towards other types of EVs.

Table 6. EV types included in the literature.

Type of EV	Reference
Plug-in hybrid EVs	[39,44,46,53,58,82,151,159,173]
Full EVs	[21–25,27–38,40,42,43,45,47–52,54–57,59–70,72–81,83–86,88–103,105–149,152,154–158,160–172,175–189,191–195]
Fuel cell EVs	[26,41,71,87,104,150,153,174,190]

8.2. Type of RES

Based on the data presented in Table 7, it can be inferred that the majority of the works analyzed involve the utilization of hybrid renewable energy systems that rely on both solar photovoltaic and wind turbine energy sources. Hydrogenation [115,132,146,189], fuel cells [26,104,127,174,194], thermal power [95,121], and biogas plant [95] are among the other limited options available.

8.3. Integration of RESs and EVs into Power Systems Targeting Emissions

EVs are gaining popularity at a rapid pace thanks to their comparatively lower emissions of pollutants in comparison with other types of vehicles. This section pertains to research initiatives that seek to mitigate emissions through the utilization of RESs' and EVs' integration. The aforementioned initiatives aim to decrease emissions through the mitigation of fossil fuel dependency [62,70,80,81,84,97,121,146,160,165,180,184].

Table 7. Distribution of published works considering RES integration.

RES Integration	Reference
PV	[21,28,55,57,61,69,72,73,86,93,106,108–110,112,122,123,126,135,137,144,145,149,152,154,156,158,172,173,178,181,183]
Wind	[27,29,33–35,43–46,49,52–54,56,74,84,91,94,97,117,119,120,124,132,138,140,143,147,148,153,166–168,170,174,176,180,192]
PV&Wind	[22–26,30,36–42,47,48,50,51,58–60,62–68,70,71,75–83,85,87–90,92,95,96,98–105,107,111,113,114,116,118,121,125,127–131,133,134,136,139,141,142,146,151,155,157,159–165,169,171,177,179,182,184–191,193–195]

The Italian energy system was subjected to modeling in accordance with a selected regulation strategy in order to optimize its technical and economic operation by minimizing primary energy consumption and CO_2 emissions, as evidenced in [62]. The work of [184], on the other hand, examines various plausible scenarios for Italy, which involve the expansion of renewable and storage capacity to meet the ever-increasing demand for electrification, particularly in the context of electric vehicles.

The work of [70] introduces a framework for possibilistic stochastic programming that combines possibilistic programming, flexible programming, and chance-constrained programming. This framework is designed to facilitate planning for the mitigation of pollutant emissions in the presence of RESs and EVs. In the work of [80], a discourse is held regarding the optimization of EVs' and RESs' employment in a power grid with the aim of reducing emissions. The article [81] presents an electric vehicle recharging mechanism that aims to decrease CO_2 emissions and improve fuel economy. Meanwhile, the work of [97] discusses a dynamic wireless electric vehicle charging system that utilizes wind power. In [121], the authors investigate a smart charging–discharging operation for cyber-physical energy systems. Lastly, the work of [180] explores the concept of a slow-charging option. The study presented in [84] investigates a multi-objective approach for economic emission dispatching, while the work of [146] examines a solution to the emission dispatch problem that incorporates risk considerations. In [160], an alternative solution is proposed for ascertaining the quantity of EVs in operation, which offers adaptable full EV functionality and mitigates emissions. The article in [165] presents a schedule for unit commitment pertaining to plug-in hybrid EVs in the context of uncertain conditions, with the aim of achieving reduced greenhouse gas emissions.

8.4. EV Charging Station—EV Parking Lot

An EV charging station is a piece of equipment that facilitates the connection of an electric vehicle to an external source of electricity. This enables the recharging of the batteries in both plug-in hybrid and fully electric vehicles. Certain charging stations possess sophisticated functionalities such as intelligent metering, cellular compatibility, and network connectivity, while others adopt a more streamlined approach and prioritize fundamental features. An EV parking lot is a designated area that is exclusively reserved for the purpose of accommodating electric vehicles while they are connected to an EV charging station. Table 8 presents a taxonomy of research works related to the integration of RESs and EVs in the context of charging stations or parking lots. Based on the information presented in the table, it can be inferred that a significant proportion of the associated research endeavors pertain to electric vehicle charging stations.

Table 8. Research works related to EV charging stations and parking lots.

EV charging station	[22,23,28,36,71,75,77,85,90,103,108,118,123,128,136,137,143,147,149,154,156,158,179,185]
EV parking lot	[24,39,100,112,182,183]

8.5. EV Batteries and Battery Energy Storage Systems

Battery energy storage systems refer to a collection of devices that are capable of storing energy generated from RESs, such as wind and solar PV energy. These systems can then release the stored energy in an efficient manner to meet consumer demand, resulting in a stable electricity supply and potential cost savings. Batteries, commonly referred to as rechargeable or storage batteries, are devices designed to store energy and have the capability to be recharged. Several distinct types of batteries can be identified, including the flow cell battery, lithium-ion battery, lithium ferrophosphate battery, lithium sulphur battery, solid-state battery, lead acid battery, and nickel cadmium battery.

The works of [23,71,137,152,155,156,159,173,178] have concentrated on enhancing the effectiveness of battery energy storage systems that are present in the sites of WT and/or PV units. The battery structures associated with graphene [31], lithium-air and lithium-sulfur [32], vanadium redox flow [67], and lithium-ion [73] are of interest. In the work of [107], a proposed scheme for managing EV charging involves battery protection. The work of [144] discusses a battery charger, while the work of [189] presents information on the effect of discharging batteries.

8.6. Control Approaches for EVs to Integrate RESs

Numerous research works have been published focusing on the most efficient control approaches for the incorporation of EVs along with RESs. The controlled charging of EVs is studied considering high wind penetration in [46] and hybrid wind and photovoltaic penetration for demand-side response in [101]. The load frequency control for EVs integrating wind and solar energy [105,129,157], or solar energy and biomass [195], is also discussed. A hybrid control approach tuned via utilizing the optimal power flow problem is proposed in [60]. A fuzzy logic controller for EVs and wind energy is proposed in [170].

A multitude of scholarly publications have been produced with a focus on identifying optimal control methodologies for integrating EVs with RESs. The study of controlled charging of electric vehicles has been examined in relation to high wind penetration in [46] and in the context of demand-side response for hybrid wind and photovoltaic penetration in [101]. The article delves into the topic of load frequency control for electric vehicles that incorporate renewable energy sources such as wind and solar energy [105,129,157], as well as solar energy and biomass [195]. The article in [60] presents a proposed hybrid control approach that has been fine-tuned through the utilization of the optimal power flow problem. The proposal of a fuzzy logic controller for electric vehicles and wind energy can be found in [170].

8.7. EV Aggregator

The EV aggregator bears the responsibility of ensuring the seamless functioning and provision of services of EVs on the electricity market. The work of [94] proposes optimal bidding strategies for EV aggregators in day-ahead energy and ancillary services markets that account for variable wind energy. The article in [110] presents an aggregator designed to effectively manage EV loads and optimize PV energy utilization through the implementation of intelligent charging protocols that leverage controllable EV demand. The literature discusses stochastic models that consider the integration of aggregated plug-in electric vehicle fleets into power systems, in conjunction with either wind energy or both wind and solar energy. These models are presented in [132,139], respectively. The literature has documented the use of aggregators for managing EVs and PV generation [145], EVs and direct controllable loads while considering various sources of uncertainty [163], and EVs and distributed hybrid RESs [175].

8.8. Cost Impact

In the work of [26], a proposed energy infrastructure is presented that is both renewable and cost-effective. The article in [46] presents a discussion on the cost reductions that can be achieved through the implementation of controlled charging of EVs. The article in [61] presents a model for dispatching production costs. A study analyzing the effects of the charging profile of electric vehicles on production costs is presented in [63]. The study presented in [65] investigates the reduction in daily electricity expenses through the integration of RESs and EVs. The topic of cost-efficient interactions between EVs and RESs is discussed in [80]. The research conducted in [160,165] explores the operations of the smart grid, which consider the discharging and charging of EVs and RESs. The aim of this approach is to achieve a reduction in both costs and emissions.

9. Algorithms and Implementation Details

Based on the analysis of 175 publications in the relevant literature, certain conclusions can be drawn regarding the algorithms employed and the specifics of their implementation. A vast majority of published research articles propose a formulation that is backed by both mathematical algorithms and heuristic algorithms. Regarding mathematical algorithms, the dominant is the mixed integer linear programming. Particle swarm optimization and genetic algorithm are widely recognized as the most commonly employed heuristic algorithms. Table 9 provides a classification of all mathematical and heuristic algorithms used in the literature, respectively. Furthermore, a considerable proportion of the suggested endeavors have been executed utilizing MATLAB/Simulink [38,85,95,97,103,105,107,114,129,135,142,157,166,170,185,188,194,195]. MATLAB/Simulink is a software tool that provides a graphical block diagram interface for creating and analyzing complex systems that incorporate multiple domains. It enables users to simulate and evaluate system performance prior to hardware implementation and facilitates codeless deployment of the system. Several optimization tools have also been adopted and the most frequently used is CPLEX, as can be concluded by the data in Table 10.

Table 9. Mathematical and heuristic algorithms used in the literature.

Formulation	Algorithm	Reference
Mathematical algorithms	Integer programming	[132,149]
	Mixed integer non-linear programming	[139]
	Mixed integer linear programming	[24,46,47,65,68,80,82,92,94,100,118,136,150,152,155,182]
	Stochastic programming	[25,50,59,65,69,70,83,100,132,163]
	Cone programming	[161]
Heuristic algorithms	Particle swarm optimization	[66,88,112,121,128,160,162,164,165,191]
	Genetic algorithm	[36,76,129,183]
	Virus colony search algorithm	[84]
	Harris hawks algorithm	[38]
	Grey wolf optimization algorithm	[96]
	Cuckoo search algorithm	[98]
	Artificial bee colony algorithm	[102,128]
	Extreme learning machine algorithm	[107]
	Alternating direction method of multipliers	[111]
	Model predictive control learning	[116]
	Parameter adaptive differential evolution algorithm	[117]
	Self-adaptive imperialist competitive algorithm	[148]
	Gravitational search algorithm	[151]

Table 9. *Cont.*

Formulation	Algorithm	Reference
	Water cycle algorithm	[151]
	Artificial ecosystem optimization algorithm	[157]
	Soft actor-critic deep reinforcment learning algorithm	[169]
	Autoregressive moving average algorithm	[178]
	Spike neural network learning algorithm	[188]
	Golden eagle algorithm	[188]

Table 10. Optimization tools used in the literature.

Optimization Tool	Reference
CPLEX	[24,25,35,42,46,47,59,65,69,73,75,80,92,94,100,110,118,132,136,138,150,152,154,177,182,192]
GAMS	[24,25,35,59,65,68,69,80,94,102,108,132,136,138,152,170,182]
EnergyPlan	[41,45,55,57,62,79,80,184,193]
HOMER	[22,28,66,71,77,87,102,128,174,181,186,191,193]
Remix	[190]
PLEXOS	[63]
PSCAD	[93]
CVX	[116]

10. Research Gaps for Future Discussion

The subsequent elements of topics that necessitate further investigation and assessment are summarized as follows.

10.1. Power System Demand

Power grids are currently experiencing strain due to the amplified utilization of RESs and the difficulty presented by the heightened variability of energy supply. The proliferation of EVs could potentially result in an augmented burden on the electrical grid, thereby requiring additional investments into grid infrastructure to effectively manage the escalating power demand. The burgeoning EV market poses a significant challenge for utilities and power generators, who must grapple with the task of predicting the timing and location of the corresponding surge in demand for electricity. Conversely, charging electric vehicles during non-peak hours, such as late night or early morning, would substantially diminish the probability of overloading the power grid.

10.2. Insufficient Capacity of Charging Infrastructure

In comparison with conventional petrol stations, charging stations present a greater challenge in terms of accessibility because of investment costs and complex infrastructure development. The installation expenses of charging stations are subject to variation based on the charger type, and additional costs such as regulatory fees and permits have contributed to the high cost of investment in charging stations. In addition, facilitating the ability for individuals to charge their electric vehicles in their typical parking locations, such as their residence or place of employment, presents its own set of obstacles. The challenges involve managing charging capabilities in multi-tenant structures, grid connections, and charging slot availability. This phenomenon has resulted in a decreased network of functional charging stations, discouraging prospective consumers from adopting EVs.

10.3. Smart Energy Management Systems

Energy management systems utilize an integrated digital platform to facilitate the synchronization of RESs, such as wind and solar power, with demand assets, including electric vehicle chargers, within an energy system. The employment of the Internet of

Things (IoT) enables the real-time monitoring of asset health and performance, thereby optimizing the utilization of RESs and reducing both operational expenses and system expenditures. Furthermore, it permits the co-optimization of EVs and permanent storage alongside others interconnected with the grid facilities. The provision of supplementary stability services of the power grid that are compatible with regional RESs is instrumental in equalizing the electrical load and guaranteeing a dependable energy supply, as well as constant market prices.

10.4. Integration of Other RESs

The focal point of research endeavors predominantly centers on the amalgamation of RESs, such as wind and solar power, in tandem with the process of electrification. The potential integration of alternative forms of energy, such as geothermal and marine wave energy, along with offshore wind farms, has yet to be thoroughly examined. However, this approach may offer viable solutions for charging EVs in remote, mountainous, or island regions that are challenging to reach.

10.5. Resiliency and Adaptability of Power Systems

Modern electrical infrastructure must possess the capacity to endure the inescapable consequences of climate change, including but not limited to extreme heat, prolonged dry spells, and severe weather events, while also being capable of responding to such impacts. It is anticipated that the ratio of energy obtained from solar and wind sources will rise, necessitating that these systems maintain optimal functionality in the absence of wind or sunlight. An adaptable power system has the capability to manage peak demand periods while ensuring an uninterrupted supply of electricity. Apart from ensuring the presence of a variety of energy sources, the system can be further improved through various means. One potential approach to enhancing efficiency involves augmenting the energy storage capacity; integrating the heating, transportation, and industrial domains in a strategic manner; or implementing dynamic pricing, smart grids, and appliances to manage demand peaks.

10.6. Wireless Charging

Automakers are likely to hit stalemates on the competitive front lines of range and charging speed as the EV industry grows. Increasing range comes with weight, packaging, and cost implications as well as stress on the already brittle supply chain for battery materials. The maximum power of charging stations will set a speed limit on vehicle charging, thus automakers will work to set their EVs apart. Many already promote ferocious acceleration, extreme off-road prowess, advanced driver-assistance features, or cutting-edge styling. However, given the variety of options consumers will soon have, even these characteristics run the risk of becoming commodities. Under these conditions, wireless charging is positioned to be a standout feature in the next generation of EVs for the brands that adopt it first.

10.7. Environmental Impact of RESs' Integration

Despite the significant attention garnered by RES systems in the fields of economics, environment, and technology in the past decade, there exists a potential for their adverse impact on the environment. As the adoption of EVs proliferates, it is imperative to conduct an assessment of the environmental impact associated with utilizing charging stations that are energized by sustainable sources of energy, including but not limited to photovoltaic, wind, hydro, biomass, and geothermal energy. This task is imperative and requires immediate attention because of its essential nature. It is imperative that the various phases of design, construction, installation, servicing, and cleaning are both technically and ecologically feasible. Furthermore, a thorough examination of the impacts that these stages exert on the environment's natural resources and biodiversity ought to be conducted.

11. Conclusions

This paper investigates the integration of RESs and EVs into energy systems. The assessment encompasses a comprehensive collection of 175 literary works that have been published within the last fifteen years, pertaining to the field of literary study. Based on a bibliographic analysis, it was found that the journals with the highest impact, as determined by the total number of papers published per journal, were *IEEE Access*, *Energy*, and *IEEE Transactions on Smart Grid*. A summary of each paper's contribution is provided, while a classification of research works pertaining to the integration of RESs and EVs is analyzed based on several factors presented in the literature. These include the type of EVs and/or RESs, the integration of RESs and EVs into power systems with a focus on emissions, EV charging stations and parking lots, EV batteries and battery energy storage systems, control approaches for integrating RESs with EVs, EV aggregators, and the cost implications associated with such integration. Focusing upon the formulation and the implementation details, it can be concluded that the majority of research articles that have been published have put forth a formulation that is supported by both mathematical algorithms and heuristic algorithms. The mixed integer linear programming algorithm and the particle swarm optimization algorithm are widely recognized as the most prominent mathematical and heuristic algorithms, respectively. A considerable portion of the studies were executed using MATLAB/Simulink, with CPLEX serving as the predominant optimization tool. Moreover, there exist several areas of research that require further exploration to enhance the incorporation of RESs into electricity networks in tandem with electromobility. The primary topics of discussion in the realm of power systems include the demand for power, inadequacy of charging infrastructure, implementation of intelligent energy management systems, integration of additional RESs, resilience and adaptability of power systems, wireless charging, and the environmental effect of RESs' integration.

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