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Review

Energy Anxiety in Decentralized Electricity Markets: A Critical Review on EV Models

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Abstract: The automobile sector is a promising avenue for enhancing energy security, economic opportunity, and air quality in India. Before penetrating a large number of electric vehicles (EV) into the power grid, a thorough investigation and assessment of significant parameters are required, as additional nonlinear and EV loads are linked to the decentralized market. Many automobile companies have already invested in electric vehicle research; hence, a detailed analysis on range anxiety and grid connectivity concerns are the important factors affecting the future of the electric vehicle industry. In this paper, the initial review is about the decentralized market in India and sustainable aspects of electric mobility based on the Indian context, as it is a developing nation with an enormous resource and scope for EV markets. With recent literature from the last three years, the substantial constraints observed in benefits and challenges are reviewed. The financial stability aspects and the incentives to overcome the barriers to EV adoption are briefly discussed. From the review, it has come to the limelight that infrastructure availability, technology, load demand, and consumer behaviour are all major obstacles in the electric vehicle ecosystem. For the overall design and study of the vehicle to grid (V2G) infrastructure, this paper also provides insight into the representation of electric vehicles in different energy-efficient models and their categorization while connecting to the grid. The methodology adopted for energy-efficient models includes lifecycle emissions, economy, smart charging, real-time optimization, aggregated EV resource modelling, and a support vector machine (SVM)-based method. This paper gives a positive impact on EV fleet integration and electric mobility in general, as it critically reviews the influential parameters and challenges. This classification depends on crucial parameters that are at the frontline of EV grid integration research. This review is a solution to enhance grid stability in regard to new EV models. With the advanced electric motors development and renewed battery technology models, longer-distance automobiles are now available on the market. This paper investigates the constraints of EV grid integration and analyzes different EV models to ease the grid stability for a decentralized market.

Keywords: decentralized market; electric vehicle (EV); smart charging; demand-side management (DSM); vehicle to grid (V2G); distributed energy storage (DES)

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1. Introduction

In 1884, English inventor Thomas Parker made the first production of electric vehicles, 25 years after the invention of lead–acid batteries [1]. Thereafter, many electric vehicle models appeared in the industry and obtained patents. Due to an energy crisis and not much technological development during the 1980s, electric vehicles could not reach high speeds or long ranges compared to conventional vehicles. However, one big challenge that is facing the environment is energy reserves and their conservation. Electric vehicles are more eco-friendly and economical in comparison with traditional cars that use petroleum or diesel fuel, as they also act as reversible energy storage devices.

The concept of efficient, smart, clean, and interconnected transport networks was largely unknown until the 1990's. During the twentieth century, greenhouse gases (GHGs) from Internal combustion engine (ICE)-powered transportation have led to degradation in economic growth, as well as environmental and social health concerns [2]. Rapidly increasing levels of GHGs in the Earth's atmosphere, along with natural calamities and catastrophic outcomes due to global climatic variations, have motivated many developed and developing nations to invest in clean and safe fuel for the transportation industry [3].

The automobile industry in India is advancing towards innovation and new trends in vehicle to grid technology. The recent developments and research are gradually catching the attention of a large and growing population for energy-efficient transportation to mitigate the severe impacts of transportation, including greenhouse gas emissions and global warming [4]. Indeed, it is a fact that electric vehicles are paving way for a positive change in the transportation industry [5]. India has a large manufacturing landscape of electric vehicles, as a large number of automakers are now taking a deep dive into the electric vehicle industry to tap the growing potential of our country [6]. The EV ecosystem offers improved opportunities in energy security, air quality, and economy [7].

Figure 1 represents the EV sales in Indian context and it shows the greater potential of the EV industry [8]. Throughout the pandemic, the revenue of the nation has been badly hit, especially the EV sales [9]. Petroleum is the major source that is providing significant revenue for the Government of India (GoI) [10]. The technology shift or transition to EV in this era requires more financial diversions. During the second wave of COVID-19, the petroleum prices in developing countries saw a major surge, affecting the transportation expense of the common middle-class people. The emission standard known as Bharat Stage VI (BS-VI) is expected to significantly impact India's vehicle industry's pollution emissions. India will be on par with the United States, Europe, and other advanced automotive markets across the world as a result of this new emission standard. Figure 1 gives an elaborate analysis of how the EV industry experienced poor sales due to COVID-19 effects from the month of May to July 2021, and the industry rise up with market relaxations after the migration to BSVI standards [11,12]. It is observed that, for the transportation services only, a large lump sum of the amount is to be paid [13]. Hence, vehicle customers are expecting a technological shift in the transportation industry. A developed primary market and a formal secondary market are very much essential to increase the resale value of EVs in the future. With so many small independent dealerships, it is challenging to build proper infrastructure for second-hand sales in the current EV market. Vehicle resale values decline over time because of handling and battery degradation, as well as time lapses in warranties [14].

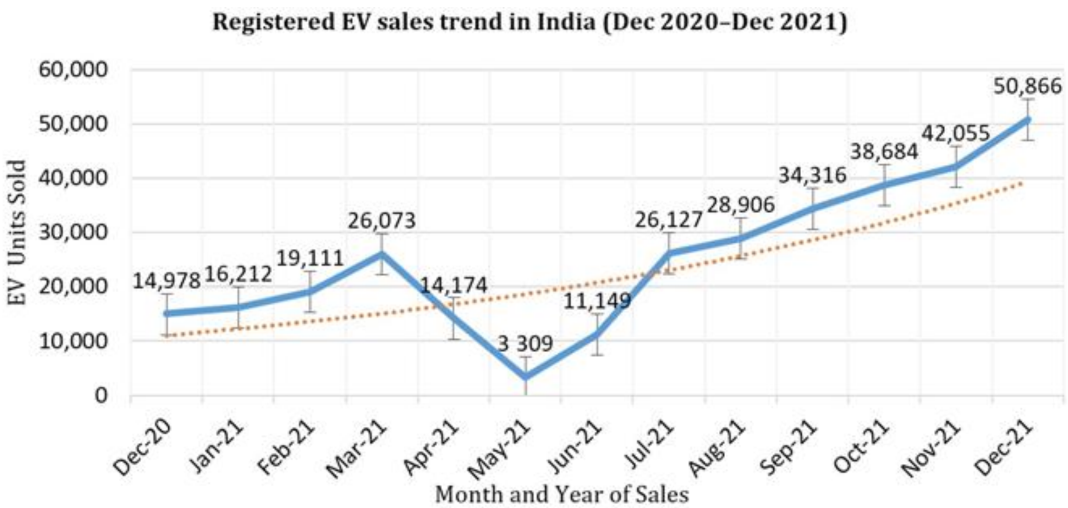

Figure 1. Sales figures represent EVs registered across 1379 regional transport offices (RTOs) in 33 states and union territories (UTs) in India.

The main research gaps observed in the existing research works regarding EV grid integration is that it does not include a detailed case study regarding decentralized energy markets of developing nations and the factors influencing grid resilience for EV models, but rather is concentrated on specific methods only, such as smart charging, IoT, and some optimization schemes, etc. The benefits and challenges of electric vehicle grid integration (EVGI) provide a more detailed selection of parameters for electric vehicle grid interconnection models. Literally no reviews were carried out with all parameters (environmental, economy, range anxiety, etc.) for EV modelling approaches in a decentralized power market. The global energy environment is confronted with numerous challenges, and data from Figure 1 clearly depicts that electric mobility will cater a significant role in the future transportation industry. The above findings have motivated the authors for this work, and the conceptualization of this manuscript is obtained from the above briefings.

1.1. Highlights of the Paper

- This paper reviews the long-term features of electric mobility in India as it is a developing nation with a lot of resources and potential for EV markets.
- This review identifies solutions to improve energy security, economic opportunities, and air quality by adopting energy-efficient, innovative models for electric mobility to reduce energy anxiety in EV grid integration.
- The electric vehicle sales study (based on the Indian context) in a decentralized environment is updated until December 2021, and grid stability concerns are addressed.
- Wide options are suggested to analyze the financial diversions in electric mobility and smart charging technologies.
- Investigates the constraints that affect the benefits and challenges during EV grid integration.
- It proposes different energy-efficient models for electric vehicles to improve grid stability in a decentralized market.
- As there were no reviews carried out on electric vehicle modelling approaches based on energy anxiety and primary parameters such as the economy, emissions, demand-side management, EV battery management systems, optimized power flow, etc. This review is a solution to enhance grid stability based on EV models.
- The initial assessment is a case study of how a developing nation like India manages decentralized electricity distribution and critically analyses the significant constraints for EV grid integration, as per 97 recent studies.
- The final stage is a categorization of energy-efficient models, after reviewing 60 peer-reviewed works with the frontline parameters of grid integration research for sustainability.

1.2. Paper Structure

The structure of the paper is organized as follows. The decentralized distributed generation in the Indian context is proposed in Section 2. The impact of electric vehicles on India's grid capacity and methods to achieve financial stability in decentralized infrastructure are surveyed in Sections 3 and 4, respectively. The intelligent smart power grids to support electric vehicle charging and grid integration are briefed in Section 5. An overview of benefits and challenges in EV fleet integration with a global context is discussed in Section 6. To solve the challenges in EV grid integration, different EV modelling approaches are suggested in Section 7. The concluding remarks and future scope of the work are drawn in Section 8.

2. Decentralized Distributed Generation in India

Decentralized Distributed Generation (DDG) sources are power-generating sources that are closer to consumer's premises; it allows the consumers to utilize renewable energy (RE) sources locally, thus reducing the maximum demand and losses in long-distance transmission. The paper [15] briefs the role of DDG for fulfilling the clean and efficient energy demands in the country, and is detailed with regard to previous data on India's power sector from 1947. It also suggests the present impression and viability studies of the Indian grid systems to completely utilize the advantages of DDG implementation [16]. By considering the case studies of solar energy integration policies in Nigeria, an expected addition of 17,800 MW by RE sources into the grid, it is expected to benefit consumers and the electricity boards during EV fleet penetration to the grid in the near future [17]. Through the benefits, case studies of other countries, application, and economics of implementation of DDG, the government is able to analyze and meet energy requirements in remote villages with renewable energy sources. Figure 2 gives significant advantages of decentralized generation for rural electrification.

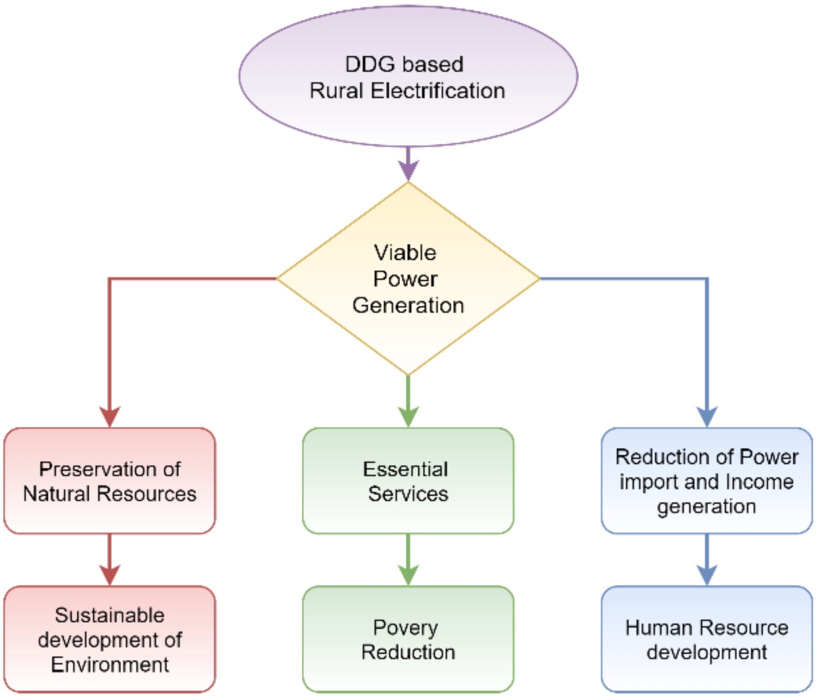

Figure 2. Various advantages of decentralized distributed generation.

The control and coordination strategies for distributed energy resources (DERs) and energy storage systems (ESSs) are mentioned in paper [18]. The control strategies for DERs, ESSs, and EVs are classified into three stages. For DERs, the primary stage is a droop-based control without communication, then a distributed multiagent control for load sharing as the secondary stage, and the third stage involves a centralized model predictive control (MPC) distributed control. The paper also suggests efficiency-based control and optimal power flow-based control for the EVs while integrating into the grid. Energy storage systems adopt an State of Charge(SoC)-based weighted droop control with competitive and cooperative control in line with advanced computational problems.

It also briefs the model predictive control of DERs and distributed multiagent-based control for DSTATCOMs. Paper [19] discusses how the large penetration of DERs to smart grids has challenges including voltage fluctuations, harmonics, voltage imbalance, etc. The interfacing issues of DDGs with smart grids, as well as the taxonomy of ESS in electric vehicles, are also mentioned. Paper [20] reports similar issues on the deregulated electricity market along with a few investigations and solution methodologies.

The implementation of distributed energy storage (DES) systems in domestic households and connecting them to the grid as per standards is going to be a solution for distributed decentralized power systems. The DES balances the demand and generation, and enhances the reliability of renewable energy loads connected to the grid [21]. In 2019, India accounted for a maximum power generation capacity of nearly 366 GW, including 84 GW of grid interconnected renewable energy. The Government of India expects to generate 450 GW of overall net electricity from renewable energy sources by 2030 [15]. In certain metropolitan cities, it is very difficult to find a place for setting up additional transformers for excess power demand. Hence, the only way is to optimize the V2G technology alongside demand-side management (DSM) activities.

3. The Impact of Electric Vehicles on India's Grid Capacity

In India, the energy sector is the main industry providing greenhouse gas (GHG) emissions (68%), followed by manufacturing processes, agriculture, food processing, forestry, etc. [22]. During grid interconnection of EV's, it can be considered as a flexible load to grid standardization, and there is also a fluctuating share of renewable energy generation linked to it [23].

Figure 3 mentions the main stakeholders and components of the EV environment, which is very critical for developing nations. The paper [24] suggests the involvement of stakeholders in the EV ecosystem, and also mentions the local and national policies related to EV adoption. India's EV ecosystem is mainly focused on surpassing the adoption hurdles related to infrastructure availability and technology cost for implementation. Financing on a large scale is another critical barrier that needs to be addressed [25]. The more interesting factor is the mindset of the large population to adapt to the new technology and present willingness; during the years 2021–2022, the transition to EVs was occurring at a slow pace [26]. A recent study has indicated that, by 2022, most consumers would consider buying an electric vehicle for fuel-efficient transportation [27]. Indeed, as petroleum prices skyrocket, the common man will think to adapt for a more economical transportation in the future.

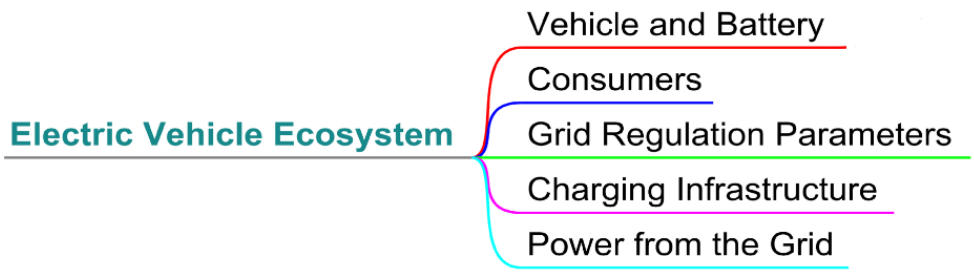

Figure 3. Stakeholders and components of an EV ecosystem.

As per 2016 World Health Organization (WHO) data, India has 10 of the 20 most polluted cities in the world. It imported 80% of the total oil requirement at 4.2 million [28] (p. 16). Nearly an average of 0.15 million people lose their lives annually in India due to road accidents [29]. Transportation sources account for one third of pollution from particulate matter (PM). Many industry experts suggest that electric mobility might happen at a rapid pace across the country, but it will require 1 to 2 years for secondary markets to expand to a whole new level. There will be a general concern related to the management of grid capacity when EVs are connected, and also the energy anxiety among consumers. India is expected to attain a 30% market capture of EVs by 2030, and the sales are also believed to touch 43 Mn [30]. The energy demand for the EV market will not pose a big challenge to the Indian energy sector, as the expected projection is only 4% of aggregate end-user demand as per research at Brookings Institute India.

As India needs about 1031 terawatt-hours (TWh) of electricity by 2030, additional reserve electric power can be attained from distributed energy resources, especially solar power [31]. As per Figure 4, if the technology shift to electric vehicles occurs, then there will be a carbon emission cut by 37%, and the overall energy requirement will be reduced by 64% [28] (p. 8).

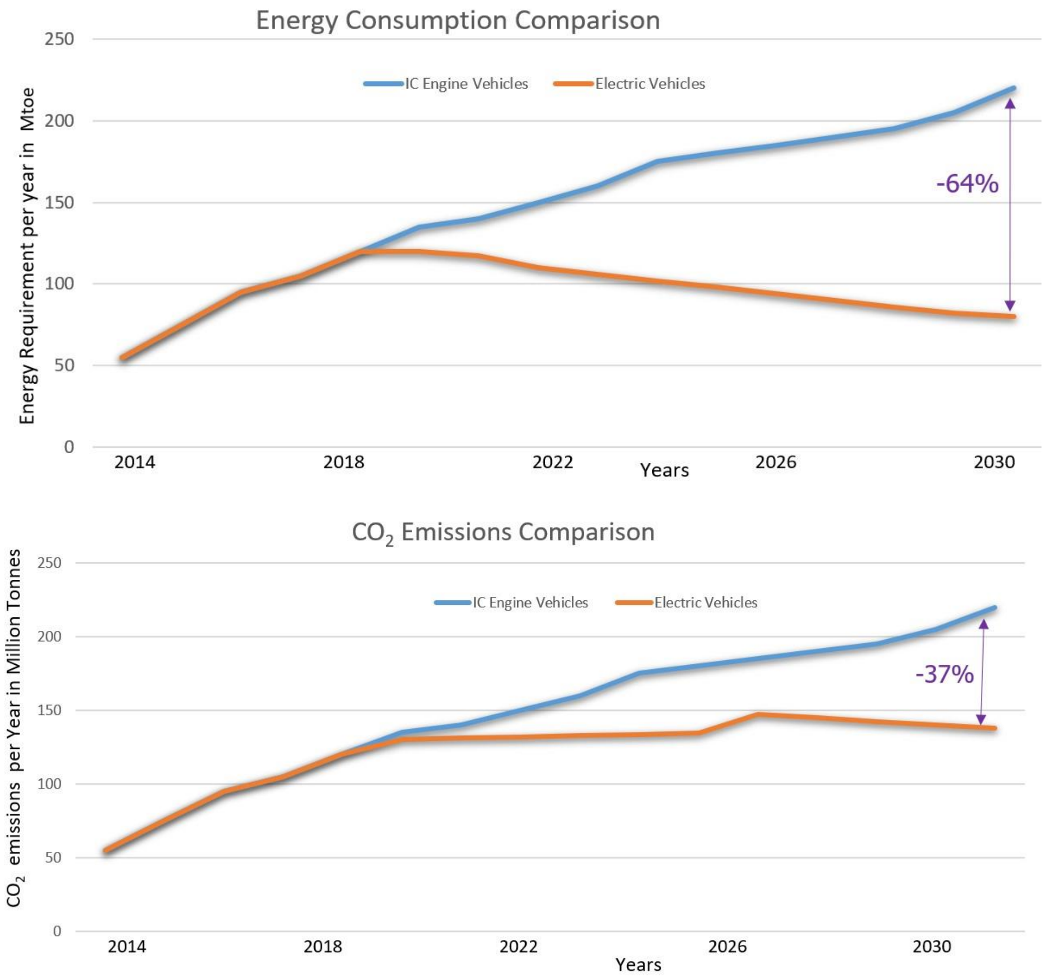

Figure 4. The variations of energy requirements and CO_2 emissions over the years.

3.1. Load Profile and Requirement of System Components

When electric vehicles are integrated into the power distribution system, some additional loads have an impact on the power grids. The supply of electric power based on demand will be a significant criterion when EVs are integrated into the grid. If charging electric vehicles is done without any planning, it will affect the load profile and maximum power demand [32]. This uncontrolled charging by EVs at any time of the day poses a potential threat to the variation of load on peak load hours [33].

Hence, with poor management of charging schedules, additional loads of EV fleet integration will affect the grid reliability [34]. The sudden overloading of existing system components can occur easily as it is not designed for additional power for EV charging [35]. The increased penetration of EV fleet charging will impact the grid's transformer reliability and lifespan [36]. In the coming years, EV battery charging from the grid is unavoidable. For that, a well-structured load management strategy and proper network planning are essential.

3.2. Phase Unbalance and Voltage Profile

Single-phase AC charging creates unbalance in the phase sequence of the network, and it is also observed that several studies have justified voltage drop and deviation from standard values in interconnection points of EV chargers [37]. The vehicle charger has a DC-link capacitor which provides reactive power through appropriate switching controls [38]. During peak load hours, V2G technology directs the energy stored in EV batteries to the electric grid, and the EV battery pack can be charged from the grid during off-peak hours. This can also provide reactive power to the electric grid [39].

3.3. Harmonics and Stability

A large number of power electronics components are available in EV charging stations. Especially during the switching operation of EV charging system, harmonics are generated in the system; however, if the total harmonic distortion (THD) generated is less than 1%, it will not significantly affect the power grid. There are several non-linear loads interconnected to modern smart grids [40]. Electric vehicle chargers are non-linear loads that introduce current harmonics into the power system while compromising power quality [41]. However, with proper EV charger design strategies, it can be used as an active filter to compensate for harmonics produced by other non-linear loads in the grid [42]. When fast charging is adopted for an electric vehicle, the harmonics injected into the electric grid become significant, and several filtering devices act as a solution to compensate for the harmonics injected [43].

The stability of the power system must be maintained steady, thereby the constraints and performance parameters of the grid are within standard limits [44]. The ability and quality of the power grid to return back the operation of the power system to a steady state is called stability [45]. The reliability of the power supplied depends on the stability of the grid. As EV charging possesses relatively new additional loads for the grid system, stability concerns have prompted many researchers to analyze and check the role of power system stability on EV charging [46]. During EV charging with the grid, if unidirectional power flows from the grid to the vehicle, major issues can occur, which can be analyzed and mitigated by bidirectional power transfer; it will also enhance the power quality of the grid [47]. Hence, with an expanding market of EVs, V2G technology realization is not just an advantage, but rather a requirement for stable power generation and distribution.

4. Achieving Financial Stability in Decentralized Infrastructure

For enhanced growth, coordination, and collaboration of V2G, different stakeholders are essential, and it is monitored by central, state governments and financial diversions are performed carefully. The stakeholders should also include persons from civil society. The National Institution for Transforming India (NITI) Aayog has proposed several suggestions for the future of EV, which included a central data-sharing platform with innovation and incubation centers for knowledge sharing. It also proposed a Unified Metropolitan Transport Authority (UMTA) at the state level [48]. The financial incentives by the Government of India and their impact on the market are given in Table 1, which indicates the financial relaxation measures for the EV industry, and how the FAME II amendment benefits the common public for EV adoption.

Table 1. Financial incentives and its impact on EV market.

Fiscal Incentives/Policies	Reference, Year	Purpose	Impact on Markets
FAME II amendment	[28] (p. 8), 2017	To promote electric two-wheeler usage in the country and expected reduced pollution.	Increased the subsidy rate for electric two-wheelers and funding to INR 15,000/KWh from INR 10,000/KWh, while also capping the incentives at 40 percent of the cost of vehicles.
National Mission on Transformative Mobility and Battery Storage (NMTMBS)	[49], 2021	Business models for improving economics for electric vehicles	Involvement of non-banking financial companies (NBFCs) in providing loans for 50% of four-wheeler vehicles and 40% of commercial vehicles.

Table 1. *Cont.*

Fiscal Incentives/Policies	Reference, Year	Purpose	Impact on Markets
National Electric Mobility Mission (NEMMP)	[50], 2018	Energy security of smart grids during EV integration.	Financial intervention for enhancing domestic manufacturing for electric vehicles.
Production-linked incentive (PLI) scheme	[51], 2022	To boost domestic manufacturing of electric and fuel cell vehicles.	INR 259.38 billion allocated for electric mobility.
State EV policies	[51], 2022	Promoting all electric vehicles.	Around 10 Indian states, including Delhi, Gujarat, Goa, Maharashtra, and Rajasthan, have already developed draft or final state-level EV policies.
New scrappage policy	[52], 2022	To reduce unfit and polluting vehicles for environmental sustainability.	By scrapping policy and increasing new car sales, the Indian auto industry will benefit and roughly INR 100 billion will be invested.

As per the statistics of the report [53], the estimated consolidated capital cost for implementing EV transition during the years between 2020 and 2030 is INR 19.7 trillion for charging stations and battery technology. In 2030, the annual loan requirement is expected to be INR 3.7 trillion. The National Mission on Transformative Mobility and Battery Storage (NMTMBS) has proposed several business models which have gained considerable acceptance and the economics of electric vehicles are improving daily [49]. This strong commitment makes India's EV market a good investment sector for innovation. The key parameters for improving the EV sector are (i) demand creation, (ii) state policies, and (iii) domestic manufacturing.

Since the 1990′s, the automobile finance sector has had an estimated worth of INR 4.5 trillion (USD 60 billion) to date [54]. Financial diversification in this sector is aided by priority-based loans from banks and non-banking financial companies (NBFCs), which account for nearly 50% of four-wheeler vehicles and 40% of commercial vehicles. The policy implemented by the Indian government, such as the National Electric Mobility Mission (NEMMP) in 2020, encourages the manufacturing of EVs and their deployment in India, along with strong information technology development [55]. It also contributes to national energy security and reduces environmental impacts. To improve EV customer attraction, charging stations can collaborate with public amenities, such as food zones, cafeterias, etc. With the help of this NEMMP plan, e-buses are permitted to operate in green corridors only, which are already prescribed [50].

As per the NEMMP scheme, more importance was given to ensure the energy security of smart grids under the control of the government. It also mitigates the adverse environmental impacts, thereby enhancing the domestic manufacturing capabilities for EV manufacturing industries [56]. A higher level of financial interventions is needed, which will re-engineer the current technology. The subsidies and financial relaxations will enhance the purchase of EVs. These financial interventions will create significant social, economic, and environmental benefits in the country [57]. Another important move was delicensing and standardization of the charging infrastructure for EVs under the Electricity Act [58]. To access the EV market, the license requirement was a barrier for small players in setting up the smart charging infrastructure. The subsidized Goods and Service Tax (GST) reduction from 28% to 12% for procurement of EV adoption is another highlighted scheme. The national e-mobility program was implemented in association with the Ministry of Power, GoI. It aimed for bulk procurement of nearly a half million government vehicles to facilitate the demand for EVs in India [59].

There exist several fiscal incentives for Indian EV manufacturers, such as reduced excise duties by the central and state governments. The additional benefits of purchasing electric vehicles in India are suggested as follows [28] (p. 8). Figure 5 denotes innovative financial incentives by the government to enhance the integration of a large fleet of EVs. It is further explained in the following subsections.

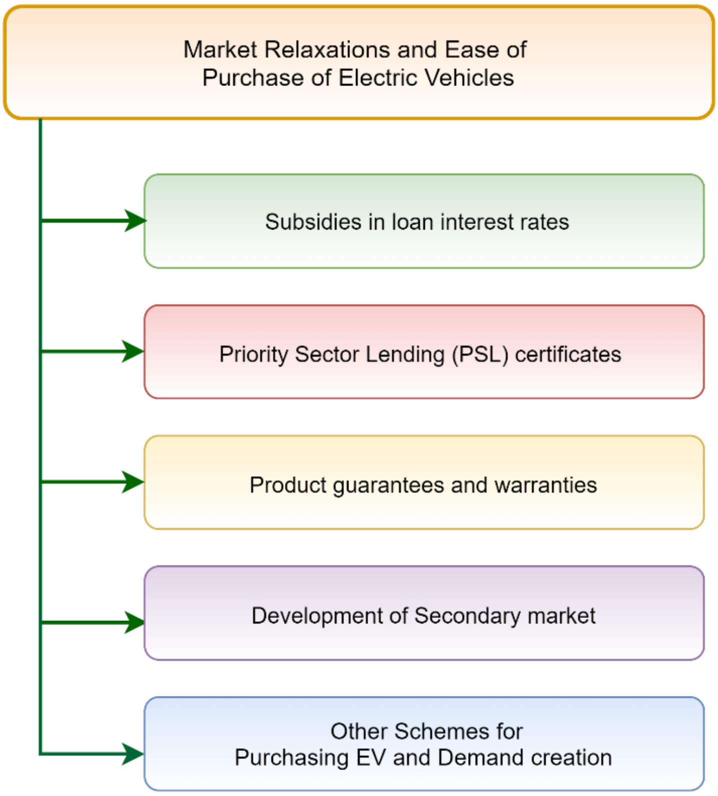

Figure 5. Represents the market relaxation offered by the government agencies for EV integration.

4.1. Subsidies in Loan Interest Rates

In paper [60], it is mentioned that the financial incentives for EV adoption depend on the lifetime cost of the EV and the type of vehicle (car, truck, etc.) purchased by the consumer. All the nations decide on the subsidies based on studies on the current EV market. The role of fiscal incentives in enhancing EV sales is carefully studied in comparison with the international markets and in consideration of the availability of raw materials for the EV industry. The subsidies will improve the willingness of original equipment manufacturers (OEMs) to take out loans, and it will also improve loan affordability. The remaining interest will be compensated by the government.

A similar system has been adopted in the education, agriculture, and housing sectors, with significant savings on interest, denoting them as priority sectors [61]. As per [62], there are a few barriers faced by consumers even after financial assistance is given by the agencies. Consumers are concerned about the availability of maintenance support even after the purchase of vehicles as it is a technology transition from IC engines.

4.2. Priority Sector Lending (PSL) Certificates

In India, as per the PSL program, the banks have provisions to allocate a significant amount of credit, i.e., 40% of net credit for small and micro-businesses, as well as five years to comply with the existing scheme [63]. Some sub-limits of PSL are also set for small businesses. Countries like Brazil, Mexico, Japan, Germany, Turkey, and South Korea adopted PSL schemes for electric mobility [63]. These initiatives will enhance the prosumers to start a business for EV sales.

The government can also prioritize EV and V2G technology of national importance, as this technology will make a big leap in the industrial revolution. In the energy sector, renewable energy is marked as a priority sector based on recommendations. Through priority sector lending (PSL) certificates, banks can easily sanction loans [64,65].

4.3. Product Guarantees and Warranties

The original equipment manufacturers (OEMs) and financial institutions (FI) play a significant role in product guarantees. The paper [66] suggests that several parameters can reduce the confidence of customer buying, such as misinformation by the dealer regarding the specification and availability of parts for the EV, lack of EV incentives, etc. As such, product guarantees and warranties are offered by the OEMs.

A sustainable EV–prosumer framework enhances the confidence of customers by fulfilling the sustainability impact of both EVs and prosumers [67]. A good partnership between these two entities will ensure a guarantee on the performance of vehicles and utilities, while dedicating financial paths for those commodities. The product warranties can be offered to buyers on a large scale initially [68]. It will assure the cost of repair and product quality.

4.4. Development of Secondary Market

By formalizing a secondary market, the resale value of electric vehicles can be increased. The OEMs can initialize refurbishment, buy-back programs, and resale EVs eventually. This model of exchange will make the EV market live and attractive to domestic customers. The most capital component of an EV is the batteries, and a secondary market for its exchange can also enhance the competition for spares in EV technology [69].

According to NITI Aayog, a framework has been proposed to the government to sell only electric vehicles in India from 2030 [70]. This would expand the emerging clean fuel technology in India and result in another industrial revolution. As the oil demand is very high, cheap transportation provisions in a developing country like India cannot afford the high import duties for buying petroleum. If India achieves 100% sale of electric vehicles by 2030, then it will reduce import duty by a large margin. As per studies, electric mobility has the potential to reduce 37% of carbon emissions and to save 64% of IC engine-based energy demand in 2030 [28] (p. 8). It will also reduce diesel and petrol consumption by 156 metric tonnes, with overall savings of nearly 3.9 trillion in 2030 according to current oil prices [71]. The road transport ministry has been asked to make a framework for electrifying the highways for selected national highways, which is called the e-highways programme.

4.5. Other Schemes for Purchasing EV and Demand Creation

In 2015, the Government of India initialized a scheme to enhance EV technology and quicker adoption of electric vehicles named the Faster Adoption and Manufacturing of (Hybrid and) Electric Vehicles (FAME) scheme. It was scheduled in two phases, FAME I and FAME II. FAME I was given funding for 0.28 million hybrid and electric vehicles at a cost of INR 9.7 billion (USD 130 million), with the goal of saving 18.49 million gallons of fuel and reducing 172 million kg of CO_2. FAME II started in April 2019, with a budget of nearly INR 100 billion (USD 1.4 billion). It was primarily intended to promote the widespread adoption of electric vehicles and newer charging infrastructure, so as to evolve an environment-friendly domestic electric ecosystem for transportation. The FAME II scheme has a greater expectation of a reduction in pollution of over 7.4 million tonnes of CO_2. The expectation in the EV industry is that the battery price is going to fall by 25–30% between 2018–2025, which will make it an affordable market over the period [17].

The new smart city planning for EV infrastructure, advanced vehicle connectivity technologies, and road network design will enhance better public transport access and it will attract ease of doing business. Increased use of electric vehicles and better public transit will improve the air quality index. The pollution issues in cities can be reduced by ensuring public health and productivity. The safe carbon emission targets set by the government can be met by these transportation solutions, as well as by accelerating renewable energy goals [72]. A more advanced connected EV ecosystem will reduce accidents, as poor road infrastructure claims nearly 0.15 million deaths on average per year [73]. India can benefit a lot from emerging electric mobility technologies that utilize high-quality public transportation and electric drive innovations to reduce the burden of direct and indirect transportation costs. Smart connecting modes via centralized data platforms can reduce congestion on roads and highways [74]. This will improve job opportunities and pave the way for rapid economic development, thereby stimulating technology development in the manufacturing section of the EV ecosystem.

5. Intelligent Smart Power Grids to Support Electric Vehicle Charging

The Smart Grid (SG) system is an integrated system that optimizes the efficiency, reliability, control, quality-of-service, and stability of power transmission and distribution via distributed computing technology with the most autonomous and adaptive communication infrastructure [75]. It has self-healing capabilities; during crisis situations of the power outage, all the electric utilities will operate in a reliable, effective, and coordinated manner. Proper regulation and load levelling in the energy market is essential as new technologies in EV charging and renewable energy sources are attached to the power grid, which will act as additional loads [76]. In this situation, smart grids provide an effective infrastructure for the regulated exchange of power, as well as the secure flow of information or data between the utilities.

A new intelligent well-connected Internet of things (IoT) platform will reshape the electric vehicle industry. The electric vehicle industrial revolution will bring profound technological shifts in the transportation network in any country [18]. Electricity will become the most efficient power source for transportation. Companies will look to see if the existing power grids are scalable, marketable, and profitable [77]. The nature of the EV industry is that consumers will have an invariable demand for electric vehicles, which will be cost-effective, reliable, safe, eco-friendly, secure, and have less maintenance [78].

The future of EV charging also depends on smart battery swapping technologies with smart infrastructure. It needs the creation of a smart infrastructure of battery swapping, where pay-per-use business models, along with integrated payment and tracking systems, play an important role [79]. The main cost of electric vehicles is dominated by the batteries. The selection of batteries for electric vehicles is based on the battery chemistry which provides optimized charging and discharging performance. The battery's material, including the electrolyte, should be able to adapt to Indian temperatures [80]. EV manufacturers could find different ways to get suitable raw materials for battery production, and also set up recycling plants for damaged batteries. The EV charging technologies will face both challenges and good opportunities for the smooth operation of smart connected power grids [81]. The major concern is that unmanaged EV charging loads on the distribution side may put a strain on grid capacity. As a result, the charging demand flexibility can be solved by implementing new smart charging methods at charging stations [82]. These methods will not only save money on grid capacity upgrades, but will also enhance the efficiency of the power grid [83].

6. An Overview of Benefits and Challenges in EV Fleet Penetration to Markets: Global Context

There are several hurdles in implementing V2G infrastructure for EV charging, despite improved economics and growth in the EV ecosystem. As EV technology is a new technology that adapts at a slow pace, it requires significant technology costs for setting up the initial charging units, aggregators, and necessary utilities for EV charging. National-level policy implementation is very essential, along with a well-coordinated state-level effort. The addition of fiscal incentives at the state level must be mentioned in the national-level policy. To increase the confidence of customers to buy EVs, and to have a favorable environment for the maintenance of parts, non-fiscal incentives are also essential. OEMs must provide greater customized products and they should be available on time, which makes the EV market user-friendly. More domestic manufacturing units and supply systems are needed at the local level for battery management systems, electric motors, motor controllers, and also other components. Alongside the industry developments, the power companies must invest in robust charging infrastructure.

Smart charging technologies are given many priorities as it communicates with the electric grid effectively and it does demand-side management [84]. Consumer behavior changes with time. Hence, by understanding the current barriers and risks associated with the EV ecosystem, there are wide options to analyze the financial diversions in this field. It should be noted that the full electric mobility concept, or the 100% electric vehicle concept by 2030 [85], is opposed by the automobile industry lobby already, as it will remove the IC engine production industry in the near future. In India, as more than 90% of road transportation is dependent on diesel or petroleum, a critical concern is that the sudden transition to electric mobility will diminish the profit of oil companies as well.

The industries which will heavily depend on these oil companies will also face a backlash with this [86]. It will also be a great concern for the government, as large revenue is observed from these fuel industries, which will suddenly be stopped with this technological shift [87]. A brief summary of benefits and challenges during grid integration is shown in Tables 2 and 3. Figure 6 represents the key parameters observed in benefits and challenges.

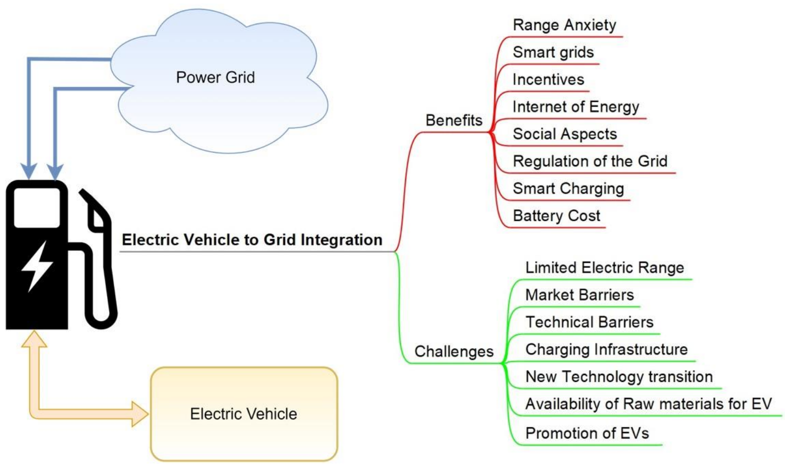

Figure 6. Key benefits and challenges as per the recent literatures.

Table 2. Benefits of electric vehicle grid integration as per the recent literature.

Benefits	References, Year	Objective of the Paper	Other Factors Contributed
Range anxiety	[88], 2021	Energy management strategies in the EV system to fuel consumption.	Integration with renewable energy sources.
	[89], 2021	Planning, operation, and configurations of charging stations for EV routing.	The existing issues and challenges of charging stations.
	[90], 2020	Customers and original equipment manufacturer's perspective on range anxiety.	Range anxiety based on Indian context.
	[91], 2019	Battery swapping.	Electric vehicle charging management options.
	[92], 2021	Environmental sustainability in comparison to IC engine vehicles.	System dynamic approach.
	[93], 2021	Inductive power transfer (IPT).	EV chargers that include on-/off-board chargers discussed.
	[94], 2021	On-road dynamic wireless charging.	A dual input buck-boost converter (DIBBC) for EV battery charging.
	[95], 2019	Several topologies used for EV charging via residential AC grid.	Interleaved AC-DC boost converter, conventional AC-DC converter and AC-DC boost power factor correction (PFC) converter compared.

Table 2. *Cont.*

Benefits	References, Year	Objective of the Paper	Other Factors Contributed
Smart grids	[96], 2021	Spatial–temporal EV charging and reliability perspective on smart grids.	A coupled system of distribution and transportation network is used.
	[97], 2021	Fog computing technology for smart grids.	SG applications, key problems, and the possible methods.
	[98], 2019	On-board and off-board electric vehicle battery chargers (EVBCs).	Challenges and opportunities for smart grids.
	[99], 2020	Artificial intelligence techniques for distributed smart grids.	Supports the integration of renewable energy sources, energy storage, and demand response.
	[100], 2019	PQ improvement in the smart grid using EVs.	The challenges brought to the smart grids by EVs.
	[101], 2019	The integration of energy storage.	Case studies with technologies and applications.
	[102], 2021	Various reliability indices to quantify the impact of EV on the smart grid are discussed.	A case study on the IEEE 13-bus system to demonstrate the impact of electric vehicles on power system reliability.
	[103], 2019	Energy management using cloud computing.	Demand-side management programs, energy hubs for EV, and power dispatching systems are discussed.
	[104], 2019	Electric vehicle charging using blockchain technology within the smart grid.	Interoperable and innovative charging systems.
	[105], 2019	Seamless integration of IoT in smart grids.	Impact of blockchain, IoT.
Incentives	[106], 2019	Incentives for EV integration: Indian context.	The main challenges and opportunities in the adoption of EV.
	[107], 2017	Electric vehicle incentives for technologies and charging infrastructure.	Electric vehicle global adoption policies.
	[108], 2021	Best practices and standards for utility grid interaction with charging stations.	Vehicle to grid (V2G) and distributed energy resources (DER) in power system operation.
	[109], 2020	Techno-economic analysis, stakeholder roles, V2G regulations.	An overview of potential grid resources for India.
Internet of Energy	[110], 2018	The economic operation of EVs with distributed energy resources using the Internet of Energy (IoE).	Connectivity issues in EV charging schemes, software tools for smart charging, challenges and solutions.
	[111], 2020	Internet of Energy (IoE) framework for distributed energy resources, various communication technologies.	Various optimization techniques and algorithms to manage DERs, and also to achieve cheaper energy prices, forecasting the faults in the grid.
	[112], 2019	The impact of IoT in power systems to overcome the grid operation hurdles and environmental challenges.	IoE in demand side and supply side of power systems.
	[113], 2020	Load forecasting and charging station recommendation.	A real-time server-based forecasting application.
Social aspects	[114], 2021	Several parameters like social class, income, and access to charging provisions affect the uptake of electric vehicles.	A case study on the UK National Travel Survey to analyze additional charging requirements on maximum demand profiles.
	[115], 2020	The socio-demographic and behavioral aspects that are linked to electric automobiles.	The biggest predictors were fuel efficiency, financial savings, and environmental benefit.
	[116], 2020	Significant obstacles to achieve EV policy goals using a risk map approach.	Integrated risk analysis approach for detecting technical, economic, and regulatory challenges.
	[117], 2020	A sociotechnical nexus connecting range, public charging, price, and mental barriers during EVGI were identified.	Identified 53 unique barriers of EVs.

Table 2. *Cont.*

Benefits	References, Year	Objective of the Paper	Other Factors Contributed
Regulation of the grid	[118], 2018	Smart EV charging network infrastructure to regulate grid power.	Adopted latent semantic analysis to build mixture user model for EV charging behavior prediction.
	[119], 2019	Bidirectional aggregator to stabilize power grid and minimize EV charging cost.	Used an IEEE 33-node distribution network for integrating five EV charging stations.
	[120], 2019	Key technologies for electric vehicle (EV) charging stations (ECSs) to control energy flow to the grid.	Optimal energy management between EVCS and grid.
	[121], 2019	DC fast charging station for electric vehicle applications.	EVCS in both grid-connected and islanded modes were presented.
	[122], 2021	Reduce peak power existing in grids by coordinated control of BESS.	A case study involving various EVCS with coupled storage systems.
	[123], 2021	Electric vehicle charging for grid planning.	Grid-friendly electric vehicle (EV) charging is integrated into probabilistic, time-series-based grid planning.
	[124], 2021	Load frequency control of multisource grid with EV load.	A magnetostatic bacteria optimization (MBO) technique was adopted for control.
Smart charging	[125], 2020	Demand charge mitigation and economic analysis using real-time electric vehicle charging.	Control of charging loads using an adaptive charging network (ACN) algorithm.
	[126], 2021	Smart charging strategy based on reinforcement learning.	Comparative study for uncontrolled charging of electric vehicles.
	[127], 2021	Adaptive charging network (ACN) algorithms enable control of EV charging and real-time monitoring.	Model predictive control and convex optimization adopted.
	[128], 2020	Prioritization of smart charging based on EV departure times.	Used trained regression models and historical data to predict departures.
	[129], 2020	Open-source algorithm for smart charging.	Algorithms are transparent and open access for development and scientific research.
	[130], 2021	Probabilistic load flow analysis of EV smart charging.	Randomly distributed and concentrated methods of electric vehicle and photovoltaic allocation are compared.
	[131], 2020	Electricity demand, spatial heterogeneity of vehicle use, and geographic network structure.	A conditional probability and convex optimization to model uncontrolled charging demand and smart charging, respectively.
	[132], 2022	Tailored choice architecture design for smart charging.	More smart charging choices based on SoC, time duration of driving, etc.
	[133], 2019	Reduces the fluctuations in charging demand and improves the demand balance.	A decision function-based strategy.
Battery cost	[134], 2019	Lifecycle of electric vehicle lithium-ion batteries.	Different recycling technologies briefed.
	[135], 2021	Disaggregated transportation cost of EV batteries and life cycle analysis.	Examined the environmental impact of end-of-life (EoL) transportation.
	[136], 2020	Challenges and opportunities for electric vehicle battery recycling.	Technical and financial challenges for recycling of batteries.
	[137], 2020	Technical and economic difficulties for battery electric vehicle (BEV) recycling.	Case studies on UK electric vehicle battery end-of-life, updated environmental regulations suggested.
	[138], 2021	An optimization model for battery charging, discharging, and battery swapping.	Based on exhaustive search and genetic algorithm.
	[139], 2019	Battery and vehicle cost analysis.	Prediction on electric vehicle costs in the United States for 2030.
	[140], 2021	Cost-effective lithium-ion batteries excluding cobalt.	Performance analysis of cobalt-free Li-ion batteries.

Table 3. Challenges of electric vehicle grid integration as per the recent literature.

Challenges	References, Year	The Objective of the Paper	Other Factors Contributed
Limited electric range	[141], 2021	Influence of battery's depth of discharge (DOD) on range.	The ambient temperature, driving cycle, load, and the initial state of charge.
	[142], 2021	Energy consumption modelling for a driving range.	Empirical relationships between different factors for EV's energy consumption.
	[143], 2021	Driving pattern recognition by electric vehicle range estimator.	EV range is analyzed based on Markov chain, along with artificial neural network (ANN).
	[144], 2020	Routing to nearby battery charging stations for the electric vehicle.	Numerical experiments in the Texas highway network are taken as case study.
	[145], 2019	Forecasting EV battery consumption based on real-time traffic data, as well as speed profiles.	On-board cloud communication and information systems discussed.
	[146], 2021	An algorithm for the electric-vehicle routing to a nearby charging station was discussed.	Nonlinear charging times addressed.
Market barriers	[147], 2019	Policies, infrastructure interventions and the outcomes of EV adoption discussed.	Market barriers to electric vehicle promotion in Ireland.
	[148], 2020	Key policies and the effects of incentives.	Case studies of EV markets in Europe.
	[149], 2021	The general perception of electric vehicles among consumers.	Electric vehicle adoption through thematic analysis.
	[150], 2020	Important mediators and moderators for EV adoption.	The EV charging infrastructure, dealership experience, and marketing strategies are addressed.
Technical barriers	[151], 2020	Limited range, reliability and performance, limited battery life, fewer EV models.	The lack of charging stations and higher cost of EVs compared.
	[152], 2019	A cost-efficiency comparison for fast charging infrastructure in EVCS.	Fast-charging infrastructure is cost-efficient.
	[153], 2020	Constraints and availability of the EV battery components.	Investigated electric vehicle business models for high adoption.
	[154], 2019	A detailed energy-economic model for EV sector.	Case study of electric vehicle penetration in European Union by 2030.
	[155], 2019	Machine learning for EV market identification.	Machine learning is used on a 5067 respondent dataset, finding 6 consumer clusters.
Charging infrastructure	[156], 2019	EV charging stations (CS) localization by explicit spatial location planning.	Spatial localization methodologies.
	[157], 2020	EV charging of ultra-low-emission vehicle (ULEV).	EVCS design, location, and cost are discussed.
	[158], 2020	New Energy and Oil Consumption Credits (NEOCC) for the charging infrastructure.	Charging infrastructure in most of the EV market dynamics.
	[159], 2020	Different levels of charging, including level 1, level 2, and DC fast charging, are discussed.	Charging behavior among different types of EV owners.
	[160], 2021	Investments in charging infrastructure with different modes.	Promoting electric vehicle adoption as per environmental perspective.
	[161], 2019	Latent travel pattern determination and charging infrastructure characteristics.	Travel behavior factors and vehicle attributes explained.
	[162], 2019	Vehicle charging infrastructure security (VCIS) retains the privacy and autonomy of stakeholders.	Communication and control methods for vehicle charging.

Table 3. *Cont.*

Challenges	References, Year	The Objective of the Paper	Other Factors Contributed
New technology transition	[163], 2019	Smart electric vehicle charging.	An adjustable real-time valley filling (ARVF) and charging control algorithm to improve PEV charging.
	[164], 2019	Smart electric vehicle with high-efficiency AC induction motors.	Sinusoidal pulse width modulation (SPWM) method for speed control.
	[165], 2019	Smart grids with bi-directional communication and concept of Internet of Energy (IoE).	Energy trading via peer-to-peer (P2P) networks.
	[166], 2019	Internet of Vehicles (IoV).	Applications, technologies, challenges, and opportunities.
	[167], 2020	The EV-IoE integrated development pathway.	Improves charging infrastructure and renewable energy integration.
	[168], 2021	Intelligent charging station in 5G environments.	The possibilities for 5G services and data privacy.
	[169], 2021	Internet of Energy (IoE) application for smart grids and smart cities.	IoE energy challenges.
Availability of raw materials for EV	[170], 2019	Raw materials supply chain study for transportation sector electrification.	Cumulated lithium demand and analysis for the year 2050.
	[171], 2022	Issues related to lithium availability and sustainability.	Future impacts on PEV technology discussed.
	[172], 2021	Factors affecting sustainable manufacturing of EV.	67 variables for sustainability discussed in Indian context.
	[173], 2021	Material supply of copper, cobalt, and nickel for batteries of EV.	The impact of raw materials on prices of EV.
	[174], 2019	Life cycle analysis of five types of passenger vehicles discussed.	A multiregional life cycle assessment.
	[175], 2018	Green technologies and reserves of raw material for the battery.	Material recycling rates are calculated.
	[176], 2019	Commercialization of lithium battery technologies.	Milestones like energy density, lifetime, safety, power, etc., are discussed.
	[177], 2018	Critical raw materials for advanced technologies.	Critical raw materials influence on environment and resource management.
Promotion of EVs	[178], 2019	An extended logistic model is used to forecast EV purchase.	Energy security constraints.
	[179], 2018	Complexity and compatibility constraints on consumer's perspective.	Characteristics of consumers and general patterns.
	[180], 2022	EV impact on profits and social welfare.	Network effect on EV subsidies, pricing, and market returns.
	[181], 2019	Enhancing the potential of small-scale markets for EVGI.	IEEE 33-node distribution grid to assess the market potential of EVGI.
	[182], 2018	Public acceptance concerns of electric vehicles.	Technical level, perceived risks, marketing, and environmental awareness studied.
	[183], 2018	The impact of electric vehicles and future energy aspects.	The comparative substantial growth of energy consumption by EVs addressed.
	[184], 2020	The role of customer experience and psychological factors for purchasing EVs.	An empirical analysis for EV adoption based on the driving experience.

Based on the availability of the information on limitations or research gaps, from the recent literature, the following Table 4 has been presented.

A strategic and systematic plan is required for the planning commission, as well as governments, to critically analyze the benefits of electric mobility and implement it. The Li-ion battery seems to be expensive as there are no domestic manufacturing units, and is also impacted by the non-availability of raw materials for the battery technology [185]. The parameters which are believed to obstruct the development of electric vehicle technology include the efficiency of batteries, range anxiety, charging time of the battery, creation of charging infrastructure, consumer perception, battery recycling, and advanced technology development for safety. Market barriers, technical aspects, and battery recycling are key parameters nowadays.

Table 4. Limitations of electric vehicle grid integration as per the recent literature.

Limitations	References, Year	Research Gaps Found	Other Remarks
Energy management in grids	[88], 2021	Optimization-based approach has difficulties in handling the constraints and using mathematical equations.	The study was limited to rule-based and optimization-based approaches.
Charging stations	[89], 2021	Challenges in ultra-fast charging and conventional stations need to be improved.	Studies on fixed, mobile, and contactless charging methods are to be improved.
Charging management	[91], 2019	Socio-economic problems associated with battery swapping in densely populated environments.	A comparative study on types of charging and swapping requires more dimensions.
	[94], 2021	The impact of charging using PV with a dual input buck-boost converter (DIBBC) should be investigated further.	The Simulink model is proposed and results are compared.
Smart charging and management	[96], 2021	The comprehensive reliability index system for the grid regulation is to be analyzed.	An EV capacity ratio to DG capacity of 3:1 for attaining system stability is adopted.
Smart charging challenges	[98], 2018	Lack of effort to identify the power quality issues in EV battery chargers (EVBCs).	Integration of an on-board EVBC into a smart home is mentioned.
Smart grid challenges	[99], 2020	Large-scale integration of DERs needs more analysis and clarity.	Instead of ANN, which is more detailed, Internet of Energy and cloud computing-based methods are to be used.
Power quality improvement	[100], 2019	More PQ issue characterizations in smart grids are to be addressed.	Due to the voltage unbalance, the uncertainties in the EV charging rates can be identified more accurately than Monte Carlo methods.
Integration of energy storage to the grids	[101], 2019	More advanced control systems for battery management must have been mentioned in the paper.	The categorization of the careful selection of energy storage is not mentioned for peak power shaving, load shifting, demand response, etc.
Energy management of smart grids	[103], 2019	Lack of research in the application of the cloud service in the demand response program.	There are not many studies analyzing cloud computing-based optimal power dispatching.
Electric vehicle charging management	[104], 2019	Lack of detailed research in the smart grid architecture model.	Blockchain technology implementation for electric vehicle charging.
Smart grid efficient operation	[105], 2019	More energy management standards are to be added rather than international standardization organization (ISO)	Apart from blockchain technologies, advanced cloud computing technologies are to be mentioned.
Grid impact on EV adoption	[107], 2017	The study conducted in the literature is a limited and preliminary case study for impacts on Delhi's power systems for EV adoption.	The review is limited to the impact on Delhi's distribution system.

Table 4. *Cont.*

Limitations	References, Year	Research Gaps Found	Other Remarks
Internet of Things-based load forecasting	[113], 2020	There are a fewer studies analyzing V2V and V2G load forecasting and charging schedule.	The communication channels for grid integration are a concern.
EV grid integration	[118], 2018	The electric vehicle user mixture model needs more data analysis.	The charging behaviour is only considered for user behaviour data.
Smart charging	[126], 2021	More research is required on the vehicle's departure time and its energy requirement.	Lack of effort from researchers to justify reinforcement learning with respect to other algorithms.
	[127], 2021	Despite its relevance in scheduled charging, parameters affecting grid stability need to be well addressed.	The scheduling algorithm is restricted to fewer samples observed.
	[130], 2021	Limited research for load flow analysis and not addressing economic parameters.	Probabilistic impact analysis needs more research data.
EV battery	[135], 2021	Literature needs more data on standard guidelines for the reuse and recycling of Li-ion batteries.	The study is limited to the United States regulatory framework.
Battery swapping	[138], 2021	Limitations of mixed-integer linear programming (MILP) for battery swapping are not addressed.	Battery swapping information is limited to nano-grids on a small scale.
EV consumption	[142], 2021	The energy consumption in auxiliary devices needs more clarity.	More parameters are required for EV range estimation.
Policies on EV markets	[148], 2020.	The lack of significant financial benefits, charging infrastructure, and model availability.	The paper analyzes electric vehicle market trends for incentives, charging availability, and promotion activities.
Electric vehicle adoption	[149], 2021.	The lack of finding all tangible and intangible gaps present in the offering (EVs) and expectations of a consumer.	The study limits the general perception of electric vehicles among consumers.
	[150], 2020.	The lack of charging infrastructure resilience, marketing strategies, charging infrastructure development, total cost of ownership, and purchase-based incentive policies.	The charging infrastructure parameters and grid stability constraints are to be addressed.
	[151], 2020.	The lack of evidence regarding EV reliability and performance.	The planning and scheduling of charging stations need more clarity.
Fast charging technologies	[152], 2019.	The lack of investigation and further developments for EV fast-charging technologies by analysis of power electronic converters, battery system modeling, and an impact on the grid and local energy storage.	Slower charging times of the battery were addressed.
EV business models	[153], 2020.	The lack of investigations in the market case for electric mobility in the current automotive landscape and challenges create an unfavourable EV market case.	The research is limited to 222 semi-structured interviews across five Nordic countries.

Table 4. *Cont.*

Limitations	References, Year	Research Gaps Found	Other Remarks
EV integration	[154], 2019.	The lack of assessments of the energy, emissions and cost impacts of various CO_2 car standards, infrastructure development plans with different geographic coverage, and a range of battery cost reductions driven by learning and mass industrial production.	Socio-technical factors are not given much weight.
Electric vehicle adoption	[155], 2019.	The lack of findings, that the vehicle to grid can contribute to the attractiveness of EVs and its pricing information for consumers.	A limited consumer market is selected for research findings.
EV charging infrastructure	[156], 2019.	The lack of findings on the charging stations and extensive empirical EV traffic data for a better understanding of the driving behaviour.	Charging station classification is based on spatial dimension only.
	[157], 2020.	The lack of evidence regarding EV reliability and performance.	The economical aspect of charging infrastructure was not mentioned.
	[158], 2020.	The lack of investigation and further developments for EV fast-charging technologies.	Limited data on public charging opportunities.

6.1. Market Barriers

When a new electric vehicle is introduced into the market, the OEMs have the responsibility to boost customers' confidence so that the servicing of the vehicle and availability of spare parts are accessible on time. The availability of a trained technician is necessary in case of maintenance or repair. The battery packs are usually expensive during the initial sales, and the availability for replacement is to be ensured to the customer [186]. Consumer perception is another factor where the choice of buying EVs is limited [187].

Hence, by using advertisements or social media, some offers or discounts may be given to the customers. Several factors have a major impact on EV integration, including the lack of knowledge of OEMs regarding the government scheme [188]. Another issue is regarding the availability of raw materials for batteries. Certain rare earth materials like lithium, nickel, and cobalt require 10–20% more consumption than materials for IC engine-related vehicles [189].

6.2. Technical Barriers

Significant technical barriers include the life span of the battery, range anxiety, charging time, the safety of the vehicle, etc. Presently most OEMs are offering a warranty of 100,000 miles/eight years for their batteries [190]. The driving range during discharging is a matter of concern if the charging stations are not available on time. A few batteries are offering a range of nearly 248.54 miles [191]. Planning trips with smart connectivity to find the location of charging stations is a viable solution for this.

6.3. Charging Infrastructure and Battery Recycling

The demand for charging stations will rise due to the increase in electric vehicles. If the charging infrastructure is less, the sales will go down. Consumers are opting for the ease of charging points and fast charging is preferred. A few manufacturers are providing charging adapters for charging at home also. It must be noted that, even if fast charging is preferred, which will take only 30 min to charge the battery, it has the disadvantage of reducing the lifespan of the battery due to high current injection within a short time. Moreover, it increases the cost of the battery [192]. OEMs are providing a warranty period for the batteries, but if the battery replacement is essential, then old battery disposal is a concern also [193].

7. Electric Vehicle Modelling Approaches

During the development stages of electric vehicles, three typical approaches exist for EV modelling: the kinematic or backward approach, the quasistatic or forward approach, and the dynamic approach [194]. These different approaches for modelling will determine the accuracy and complexity of the model. To conclude the model, a general description of certain physical situations and their relation to the system is required.

It is to be noted that, while considering the different modelling approaches of electric vehicles, a few parameters are affecting the benefits and challenges during EV integration. This review is an insight into the various modelling approaches based on recently published significant research works. Figure 7 represents a general outline for energy-efficient EV modelling to the grid. Figure 8 categorizes different energy-efficient modelling approaches based on critical parameters such as forecasting, modelling, design, and optimization. The relationship between subsystems is described using correlations or mathematical expressions, and the quantities observed in the equations are interpreted either as different parameters, constants, or variables. Parameters can be determined or may be predefined, and variables that are not known need to be calculated.

The classification of electric vehicles as different models based on energy performance and influential parameters in the field of grid integration research is summarized in Table 5 with notable references. Older studies are included in the review because the base modelling concepts of EV cannot be ignored.

Table 5. Modelling approaches of electric vehicles during the grid integration.

Model	References, Year	Factors Considered in the Paper	Remarks
Life cycle emission model	[195], 2014	Air quality monitoring in Indian cities, health impact, clean energy.	Emission Sources and Control Options for better air quality in Indian cities briefed.
	[6], 2014	EV scenario for minimum carbon emission in India, insight to smart grids, batteries.	EV urban transport options in India were detailed.
	[196], 2011	Reduction in toxic emission, energy storage options, Denmark case studies.	Flexible energy storage options during the interaction between power system and the transport system.
	[197], 2013	Benefits of integration to RES to reduce air pollution.	Grid impact due to EV reviewed, balances the excess renewable energy by EV integration.
	[198], 2021	Emission reduction techniques suggested.	Energy harvesting with EV.
	[199], 2017	Socio-technical system for electric mobility, socio-environmental advantages.	Mentions techno-economic perspective.
	[200], 2021	Boosting storage support for renewable energy-based grid systems.	Case studies on Integrated hybrid energy storage in university campuses.
Economic model	[201], 2015	A solution to non-linear EV prices and charging optimization.	Robust optimization approach.
	[202], 2016	Economic operation and cost optimization.	Mixed integer linear programming (MILP) approach.
	[203], 2017	Techno-economic analysis, EV based on energy storage.	Ancillary service markets in UK as a case study.
	[204], 2021	Economics of charging station.	k-level nested quantal response equilibrium model.
	[205], 2019	Charging/discharging price regulation in home energy management systems.	G2V, V2G, and V2H case studies observed with 11.6% reduction in electricity cost

Table 5. *Cont.*

Model	References, Year	Factors Considered in the Paper	Remarks
Load forecasting and maximum demand model	[191], 2016	Charging demand for EV.	Historical traffic data in real-time and weather data were used.
	[206], 2016	Forecasting based on customer profile and charging station, EV speed, accuracy privacy concerns with respect to different charging stations analyzed.	Four different prediction algorithms namely time weighted dot product-based nearest neighbor (TWDP-NN), support vector regression (SVR), modified pattern sequence forecasting (MPSF), and random forest (RF) used.
	[207], 2019	Solves an online optimal charging problem to reduce total system energy cost.	MPC-based optimal scheduling and charging based on fuzzy rules.
	[208], 2014	Minimizes the cost of energy consumption, while respecting EV consumer preferences.	Model predictive control approach allows EV users to be involved in demand-side management (DSM) programs.
	[209], 2019	A pricing and scheduling mechanism to estimate and track the stochastic price and regulation signals for load forecasting.	A mixed Bayesian-diffusion Kalman filtering strategy.
	[210], 2013	Short-term steady-state forecast of a smart grid for adaptable EV loads.	Forecasting the power production by Bayesian-based approaches to RES and various load demands.
	[211], 2016	Short-term load forecast in medium-voltage/low-voltage distribution systems.	Neural network-based model design, case studies of French distribution systems.
	[212], 2019	Short-term load forecasting extracts complex and important features of load sequences by periodic coding.	Multi-scale convolutional neural network with time-cognition (TCMS-CNN).
	[213], 2019	Short-term power load forecasting strategy. Forecasted the seasonal load and compared it with long short-term memory (LSTM), support vector regression with back propagation models.	Multi-layer bidirectional recurrent neural network.
	[214], 2017	Large-scale advanced metering infrastructure data collection.	Hierarchical K-means method.
	[215], 2019	Uncertainty analysis of electric load when loads are connected to smart grid analyzed.	Improved quantile regression neural network.
	[216], 2021	Peak demand management in LV residential networks.	Mixed-integer programming optimization minimizes the cost of energy for EV users.
Smart charging schedule strategy and quadratic optimization model for EV connected to grids (battery model)	[217], 2020	Five important lithium-ion battery models such as empirical, electrochemical, equivalent circuit, data-driven models, and reduced-order models are analyzed.	Performance parameters of battery determined using electro-chemical impedance spectroscopy (EIS) test.
	[218], 2011	The relation between mathematical and circuit-oriented battery models is analyzed and a differential study is performed.	Modelling based on mathematical and circuit-oriented approaches.
	[219], 2021	An EVCS comparative analysis is performed between the Indian and International standards.	Recommends the combined charging system (CCS) charging methodology to reduce charging costs.
	[220], 2016	V2G advantages, unit commitment (UC) optimization strategies adopted.	A summary of main optimization techniques satisfying multiple constraints in V2G.

Table 5. *Cont.*

Model	References, Year	Factors Considered in the Paper	Remarks
	[221], 2015	Types of computing services for big data analysis and information management for smart charging and EV integration.	Cloud computing-based framework for smart charging.
	[222], 2017	Operating cost optimization in an interconnected nano-grid (ING).	A mixed-integer linear program (MILP) is formulated to analyze the economic operation.
	[223], 2012	Time-resolved energy consumption in EV and fueling cost is measured for plug-in hybrid electric vehicles (PHEV).	The time-of-use (TOU) rates during peak charging were studied by a consumer decision tree model.
	[224], 2018	Factors to maximize the potential range of battery life are discussed.	A continuous quadratic programming model is used to determine the optimal charging (OPT) of the battery.
Real-time optimized EMS model for electric vehicles with smart charging modes in the power grid (battery model)	[225], 2004	Microgrid and dynamic loads design.	Waste heat recovery is also performed.
	[226], 2015	The implementation of peak shaving functions on EVCS.	A customized communication protocol for smart charging using LabVIEW.
	[227], 2017	State of charge (SOC) and state of health (SOH) estimation techniques.	Enhanced coulomb counting algorithm and Kalman filter methods.
	[228], 2009	Estimation of the state of charge (SOC) and state of health (SOH) for valve-regulated lead-acid (VRLA) batteries.	Battery analysis at the depletion and charging states with respect to maximum releasable capacity and the charged capacity.
	[229], 2020	Energy management in electric vehicles with V2G. Optimization of the EVs' charging (G2V) or discharging (V2G) profiles.	Multifactor optimization of smart grids mentioned.
Aggregated EV resource modelling for load levelling and regulation in power grids (V2G model)	[84], 2010	The potential benefits and impacts of electric vehicles grid integration under steady-state and dynamic behavior.	Market operation framework for EV integration.
	[199], 1997	Analyzes EV battery storage based on three various driving requirements.	There would be substantial economic benefits for batteries of EVs as an energy source when compared to internal combustion engines.
	[230], 2013	Long-term impact of EV grid integration on the generation side, determination of cost of EV charging.	Generator scheduling is performed by a new unit-commitment algorithm.
	[231], 2020	A lithium-ion battery degradation non-linear model enhances the lifetime of EV charging.	The lithium-ion batteries degradation factors on the operating conditions were analyzed.
	[232], 2015	Smart charging mechanism with vehicle to grid frequency regulation services.	An EV aggregator in a queueing network is modelled.
	[233], 2020	Electric vehicle charging standards and its influence on grid voltage regulation.	A summary of all international standards for EV integration.
	[234], 2017	Co-ordination of aggregator in EV resource modelling, V2G power levels, and peak Shaving.	Effect of EV mobility attributes on grid co-ordination.
	[235], 2019	Determines the two-way energy storage capacity of a fleet of electric vehicles (EVs) which can be contracted in the ancillary services market.	A model representing battery electric vehicle (BEV) with minute-wise storage capacity provides frequency regulation to the grid.

Table 5. *Cont.*

Model	References, Year	Factors Considered in the Paper	Remarks
	[162], 2014	Minimizes the cost of vehicle battery charging, estimates costs of battery degradation.	Uses a simplified lithium-ion battery lifetime model.
	[236], 2021	The SVM is used to model the battery nonlinear dynamics, tests are performed on an 80Ah Ni/MH battery pack.	The simulation of the SVM model for better battery efficiency dynamics with less experimental data.
	[237], 2021	Gaussian process (GP) is used to determine the uncertainties of battery state estimation. This model optimally manages energy flow within power sources of the vehicle in real-time.	A novel learning-based model predictive control strategy (LMPC) was adopted.
	[238], 2009	Classification and detection of power quality disturbances by SVM.	Many transient disturbances like voltage sag, interruption, swell, harmonics, swell with harmonic, sag with harmonic, and flicker, are tested. Sensitivity analysis is performed under different noise conditions for the algorithm.
An SVM-based model for mitigating PQ disturbances in V2G infrastructure (V2G model)	[239], 2013	Intelligent power quality (PQ) issues are differentiated using various signal techniques to enhance power quality.	The digital signal processing tools applied for feature extraction include Fourier transform, wavelet transform, Stockwell transform, etc. The optimization techniques used include genetic algorithms, simulated annealing, particle swarm optimization, and ant colony optimization.
	[40], 2011	The influence of battery charging systems on the grid's power quality in a smart grid environment is analyzed. Two different types of EV battery chargers, traditional and smart charging, are compared.	As per the electric consumption profile, the voltage degradation for a large number of houses was observed during experimentation.
	[240], 2016	The classification of combined and single PQ disturbances is mentioned. The time and the recognition accuracy of PQ issues were improved.	Employs a number of binary SVMs to test a variety of signals.
	[241], 2015	Estimates single-phase and three-phase power-quality indices.	Uses the application of an empirical wavelet transform (EWT)-based time-frequency technique.
	[242], 2020	EV charging model formulation.	The magnitude of the voltage fluctuations, location in the grid, PV capacity, and effects of power quality were studied.
	[228], 2013	The exploitation of lithium for energy storage is discussed.	The mineralogical aspect and lithium extraction process are discussed for future EV battery usage.

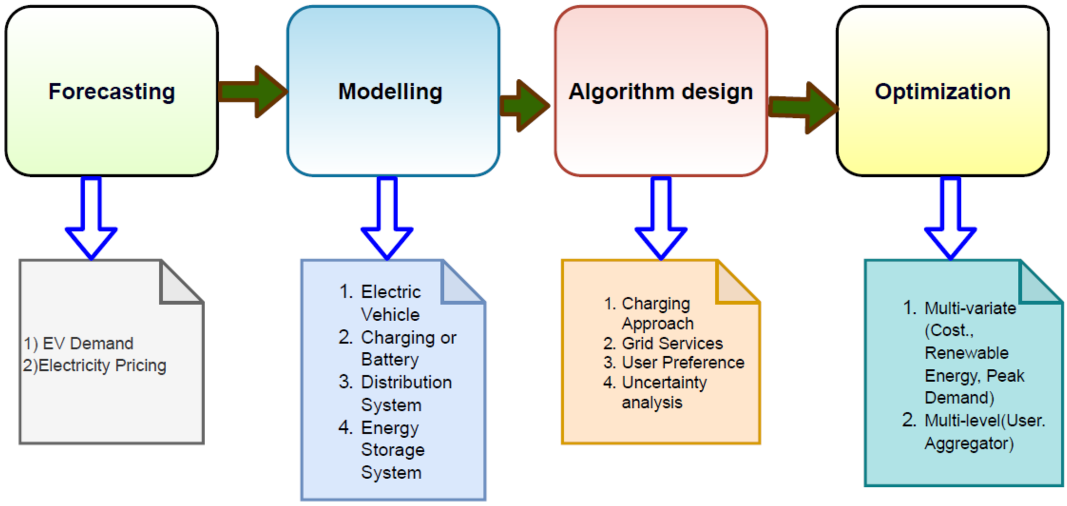

Figure 7. A general outline for modelling a grid-connected EV charging schedule.

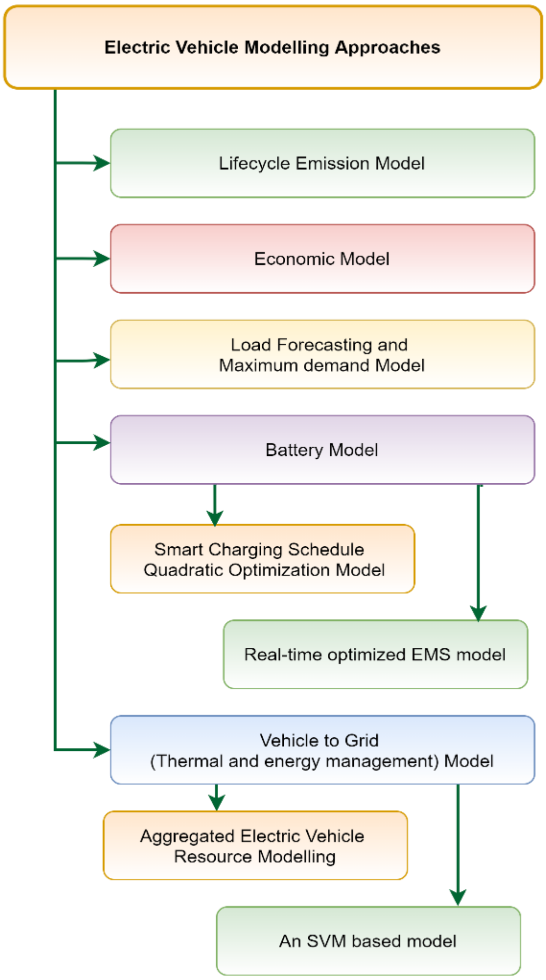

Figure 8. Classification of the various modelling approaches based on certain critical parameters.

Based on the availability of the information, the categorization of modelling electric vehicles based on methodology, the advantages, and limitations has been presented in Table 6.

Table 6. Categorization of modelling electric vehicles based on methodology, advantages, and limitations.

Modelling Approaches for EV	Methodology Adopted [Reference]	Advantages	Limitations
Life cycle emission model	Energy harvesting methods, thermo-electric generator, and waste heat recovery schemes. Regenerative breaking [198].	Air quality monitoring, clean energy, reduction in toxic emission.	Limited to energy harvesting methods in hybrid electric vehicles.
Economic model	Techno-economic analysis using Monte Carlo-based methods. Mixed-integer linear program (MILP) can be also used for cost optimization [205].	Economic benefits of planned EV charging and discharging.	Lack of effort to clarify the pricing of EV charging/discharging.
Load forecasting and maximum demand model	K-means, artificial neural network (ANN), Bayesian approaches [209–216]	More information details regarding short-term steady-state analysis of load forecasting are available.	All literature is limited to one approach only.
Smart charging schedule strategy and quadratic optimization model for EV connected to grids (battery model)	Cloud computing-based smart charging [218,221,222].	More coordination between the grid operations and charging stations was observed.	More research needed for regression extraction strategy for battery models.
Real-time optimized EMS model for electric vehicles with smart charging modes in the power grid (battery model)	Real-time optimization algorithm for energy management using four modes of operation [229].	The charging modes adopted are energy efficient and save time in the parking lot.	Lack of information on battery degradation to determine the charging power profile.
Aggregated EV resource modelling for load levelling and regulation in power grids (V2G model)	Power scheduling activity by aggregator for scheduled charging and load balancing [232–234].	The EV standards and charging structure is well explained with more data on V2G frequency regulation.	The economics related to EV charging is to be mentioned.
A support vector machines (SVM)-based model for mitigating PQ disturbances in V2G infrastructure (V2G model)	Using support vector machines and supervised machine learning algorithms [236–238]. Generalized empirical wavelet transform (GEWT) also adopted [240].	The classification of PQ disturbance is observed and the mitigation process is satisfactory.	New advanced technologies like cloud computing have to be mentioned in a section.

7.1. Lifecycle Emission Model

The toxic gas resulting from air pollution has forced certain governments to take necessary action to review the situation seriously and think of a new technology that provides emission-free transportation. In a 2014 assessment, the World Health Organization (WHO) named New Delhi as one of the top ten world cities with the worst air pollution [195]. The paper [6] reviews several stages in EV lifespan and recommends suitable policies to lower emissions in transportation, along with the case study of the national capital New Delhi. An analysis of greenhouse gas (GHG) emissions was compared between conventional and EVs in the paper [243].

The overall emissions over the entire lifecycle of any vehicle depend on wells-to-wheels emissions. Several case studies suggest a good reduction in toxic emissions; for instance, in the case study of Denmark, a significant reduction of 85% CO_2 emissions was observed [196,197]. Many research papers conclude that EVs have fewer wells-to-wheels emissions [198,200]. By boosting storage support for unstable renewable energy sources, vehicle to grid integration systems can provide further socio-environmental advantages [199].

7.2. Economic Model

A cost-effective model with a techno-economic analysis for energy storage is essential to determine the economic feasibility of EV integration [203]. Monte Carlo-based analysis is very effective to evaluate the economic status of EVs with grid connectivity. Other methods like the mixed-integer linear program (MILP) can also be used for economic operation and cost optimization when EVs are connected to nano-grids [202]. To reduce the charging cost and to minimize the EV charging loads, an optimized robust charging schedule is effective [201]. Optimal placement of charging stations will promote critical public acceptance of EVs, and it is also an economically feasible solution for distance charging [204]. The home energy management system (HEMS) can also contribute to the financial benefit of EV mobility. It will be effective when grid to vehicle (G2V) is operational during off-peak hours and vehicle to home (V2H) is operational during peak hours [205].

7.3. Load Forecasting and Maximum Demand Model

Load demand of a particular area is to be carefully analyzed with all the prehistoric data and a few case studies of EV on a daily or weekly basis of sample data [191]. For comparing the availability of EVs in a charging station, various algorithms can be used, which also optimizes the required charging patterns [206]. The hybrid model predictive control method is effective in calculating minimum peak demand control [208]. An IEEE 15-bus distribution system for load management was discussed in the paper [207] as a case study. For decades, numerous parametric models have been chosen for predictive demand load modelling, such as K-means, artificial neural network (ANN), and Bayesian approaches, and they bring significant results [209–216].

7.4. Battery Smart Charging Model

7.4.1. Smart Charging Schedule Strategy and Quadratic Optimization Model for EV Connected to Grids

The smart charging strategy is very efficient and it enhances the reserve capacity of power in electric grids to maintain load levelling. Selecting a suitable optimization method is a viable solution to lower the charging cost in EVs [217]. Without the help of smart charging, integrating the fleet of EVs into the grid may result in disadvantages, as it will be an additional load on the electrical utilities which are presently managing the load levelling and regulation [219]. By smart charging, EVs can be scheduled to be charged automatically in off-peak times, and active power support to the grid can be made available during peak hours [220]. A new cloud computing-based method implemented on nano-grids will serve the functionality of smart charging easily [221,222]. For all optimization strategies, for charging there exists a problem statement for the mathematical model. Using a smart scheduling strategy, the objective function for optimization can be initialized [218].

In general mathematical notation, the minimum load in the power grid is: $min(P_{grid}^2)$

$$P_{grid} = P_{load\ profile} + P_{charging} \tag{1}$$

where P_{grid} is grid power is denoted in (1), $P_{load\ profile}$ is the everyday power demand of a region/area without charging power for EVs, and $P_{charging}$ is the charging power of EVs.

The charging during off-peak hours will reduce the electricity bills to a much lower amount, and also ensure grid stability and reduce the power demand on the consumer's end [223]. The quadratic programming approach also ensures a minimized cost of charging schedule and maintains a predefined SoC of EV battery, even after allotting power to different utilities in the grid [224].

7.4.2. Real-Time Optimized EMS Model for Electric Vehicles with Smart Charging Modes in the Power Grid

As electric vehicle charging stations are designed and implemented at a faster pace than ever before, the reliability of the grid must be optimized by energy management systems (EMS), and cost-effective smart charging modes are to be utilized in V2G infrastructure [226]. The microgrid consists of a network of different loads like dynamic loads, PV loads based on maximum power point tracking, and EV charging stations, etc. [225]. Four EV charging modes with different user options are suggested in this EMS model, including energy/cost efficiency or ultra/fast charging. The dynamic programming in real-time is analyzed to optimize the charging of EV batteries in ECO and V2G modes. This model formulates the cost function and studies the characteristics of EV battery charging parameters like the state of charge (SoC), depth of discharge (DoD), etc. [228,244]. The effect of V2G systems on the lifespan of EV batteries depends on battery degradation parameters and the total cost of ownership of different EV charging modes [245,246].

EV users have the option to select different charging modes, and EMS communicates to converters through a communication channel; real-time battery information is required for energy management. Figure 9 illustrates four EV modes of charging denoted as ULTRA, FAST, ECO, and V2G with powers from the grid as P_U, P_F, P_E, and P_{V2G} [229]. The function of EMS is to measure the power grid parameters and transfer the individual charging signals based on an optimization algorithm.

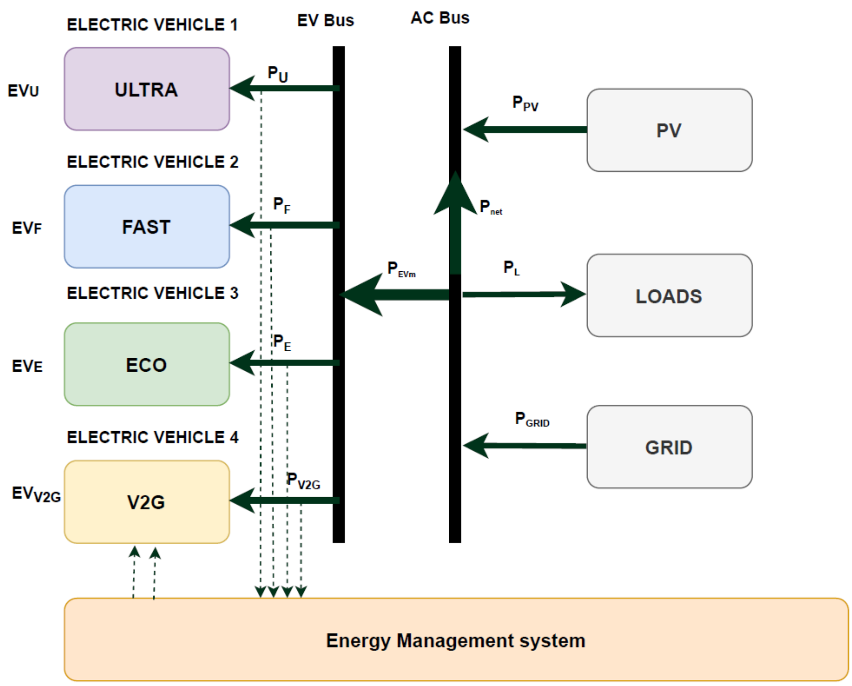

Figure 9. Arrangement of the EMS-based microgrid model.

The power balance Equations (2) and (3) of the arrangement are written as

$$P_{grid} = P_{net} + P_{EVm} \tag{2}$$

The resulting power between demand and generation is

$$P_{net} = P_L - P_{PV} \tag{3}$$

where P_{grid} is grid power, P_{net} is overall net power in V2G, P_L is the power of additional loads, P_{PV} is power from renewables, and P_{EVm} is the overall power for the EV Fleet.

ULTRA mode charging is for users with high priority, and it is for a shorter duration with demand not exceeding the saturation value. Here, a maximum permissible power charger is supplied. The FAST option is available to those who do not wish to spend as much as ULTRA mode, and priority-wise, it is less than ULTRA mode. No prediction data is available in this mode. ECO mode is for users with minimum cost and charging, with lower priority than previous modes. V2G mode has complex control, and it satisfies both grid and EV battery. The predicted data of energy flow is taken into account, and this mode supplies power to other vehicles when ULTRA/FAST charging requests are not handled by the microgrids. When energy demand reaches a saturation point, higher priority modes are only enabled by EMS optimization.

7.5. Vehicle to Grid (Thermal and Energy Management) Model

7.5.1. Aggregated EV Resource Modelling for Load Levelling and Regulation in Power Grids

Energy security for the long term is an essential element for a sustainable future in growing transportation consumption. A fleet of EVs is a significant energy resource for the power grid as vehicle to grid (V2G) and grid to vehicle (G2V) modes of battery charging will increase generation adequacy and provide flexible energy storage in the order of megawatts. The model suggests a method to determine the bi-directional storage capacity of electric vehicles, and also to enhance the voltage regulation to the grid [199]. The standards in charging and discharging directly influence the voltage regulation of the grid [233]. By this scheme, a notable revenue can be expected for a long-term energy capacity commitment [230].

EV scheduled charging using V2G reduces charging costs and emissions. A centralized charging scheme would allow more EV integration into the grid [247]. An aggregator is an entity that controls a large fleet of electric vehicles and is the reason for integrating EVs into the power grid to balance the load and generation [234]. The performance parameters in the charging and discharging stages are monitored using algorithms, and minute-wise energy storage capacity of the deregulated electricity market is analyzed, keeping constraints like arrival, departure times, travel and parking duration, etc. By the momentary fluctuation of energy data observed between power supply and demand, an accurate system-wide frequency is stabilized. By modelling the charging and discharging patterns, the non-linear characteristics of lithium-ion batteries are designed [231].

The grid regulation has two modes, regulation down (RD) and regulation up (RU), where regulation up occurs when the demand exceeds supply, and regulation down occurs when supply surpasses demand, so as to nullify the grid imbalances momentarily [232]. The charging/discharging power, trip distance, and arrival patterns are several parameters that influence RU and RD. The grid regulation depends on the availability of vehicles, as well as the expected mileage of the available EV aggregation at various charging places. Figure 10 represents the schematic overview of an aggregated storage strategy for power scheduling.

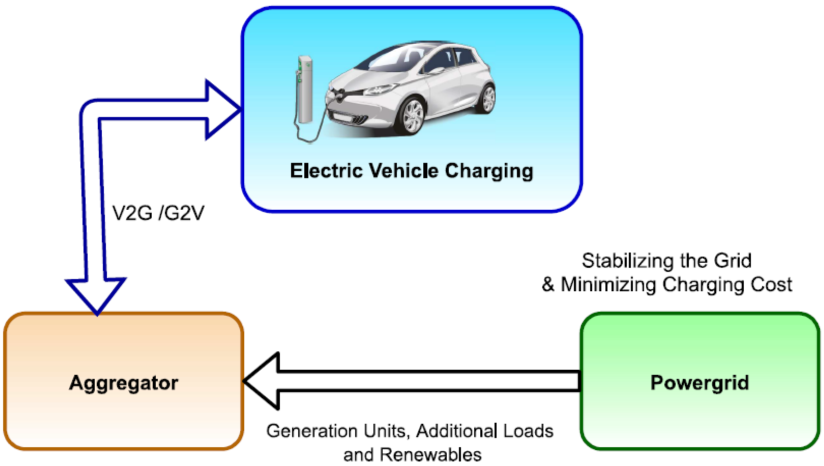

Figure 10. Overview of aggregated storage strategy.

Figure 11 is a block diagram that represents the power scheduling activity by an aggregator. The input stage involves collecting data on vehicle information, like fuel economy, vehicle capacity, arrival timings, driving mileage, etc. The information is given to data acquisition, which analyses and computes the charge and discharge energy storage capacity of electric vehicles available at various stages of parking. The G2V and V2G power selection constraints include vehicle capability, available parking, charging infrastructure, etc. Different ancillary services markets are committed to the output energy storage capacity via aggregated connected channels.

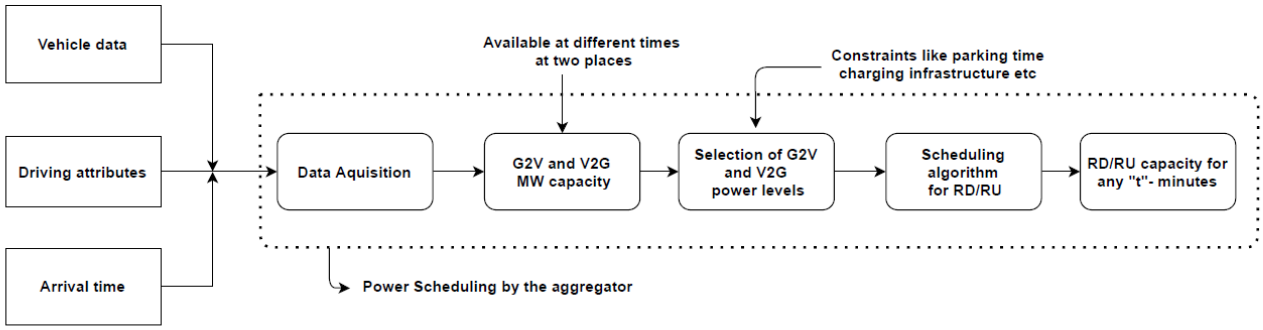

Figure 11. Schematic of the aggregator's power scheduling activity for EV resource modelling.

Hence, apart from improving grid dependability, the model also analyses the coordination of grid connection with EV aggregation, thereby increasing opportunities in the competitive deregulated electricity market for new EV integration also [235]. The simulative model for instantaneous power scheduling (minute-wise) helps to attain storage capacity via a large fleet of EVs. It also presents wide opportunities for a large number of EVs in this network, and enhances the regulation capacity commitment of the grid.

7.5.2. An SVM-Based Model for Mitigating Power Quality (PQ) Disturbances in V2G Infrastructure

As electric vehicle charging technology is advancing to smart techniques, power disturbance mitigation is also an important parameter to be considered when the electric vehicle is connected to charging stations [242]. Moreover, power electronic components in the vehicle, as well as the charging station, generate more PQ disturbance, which will significantly affect the EV battery life if it is not compensated on time [162]. Figure 12 denotes a supervised machine learning algorithm-based model; i.e., for the categorization and analysis of independent and combined PQ disturbances, the support vector machine (SVM) models can be utilized in EV charging and discharging [236]. The detection, classification analysis, and regression of performance parameters in EV charging can be easily computed by SVM [237]. The important advantage is that the most promising and probable PQ disturbance can be sorted out, and it can be analyzed and mitigated separately with SVM models [238].

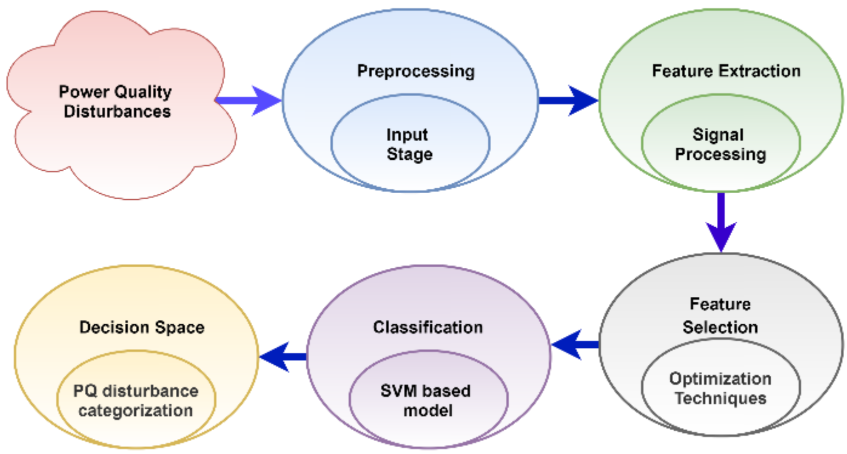

Figure 12. The several stages of power quality disturbances classification by SVM.

In general, significant disturbances similar to voltage sag, interruption, swell, and transients exist in charging modules, but the probability of impact on regulation and load variation is negligible [40]. However, when a large fleet of vehicles is considered, the PQ disturbances in the system will become significant, as many different non-linear loads are present in the grid. Initially, signal processing techniques are required for diagnosing PQ disturbances by Fourier transform (FFT), discrete wavelet transform (DWT), wavelet packet transform (WPT), etc. [239]. Out of these techniques, generalized empirical wavelet transform (GEWT) has gained more significant attention due to its simpler adaptive filter design [240].

The power signal for charging has a fundamental frequency component, and it is decomposed to mono-frequency components by GEWT. These methods adopted are computationally less expensive when compared with conventional approaches. The SVM model process the linearly inseparable input data so that a kernel function K (u_i; u_j) is used to create a high-dimensional space feature. A separate complete analysis of PQ disturbance is possible by using the SVM model with GEWT [241]. It is observed that the combined detection of PQ issues reduces the overall accuracy [227]. Many SVMs are employed for PQ analysis in power grids, and separate SVMs are assigned to detect and analyze single disturbances. The signals generate fundamental frequency variations of the order of ± 0.25 Hz at various phase angles. Due to the computational efficiency and adaptiveness of GEWT, it is also selected for evaluating non-stationary signals; hence, SVM-based PQ analysis.

8. Conclusions and Future Scope

In the first part of the review, the benefits of electric vehicles, such as reduced toxic emissions, and lower fuel, operating and maintenance costs, were basically an insight into the challenges and barriers in EV adoption to the decentralized market. In general, the definition of decentralized electricity markets in association with DERs was discussed; moreover, several EV models on the basis of energy performance and influential parameters were categorized, along with case studies of a few countries. The classification of electric vehicles as different models was done based on critical parameters which draw more attention in the field of EV research. As EV technology is growing so fast, the ability of grids to automatically stabilize the necessary constraints will help the V2G ecosystem to add more EV fleets into it for charging, thereby reducing energy anxiety. This work is mainly concentrated on the generalized structure of decentralized markets and the impact of EV fleet integration into the grid. Hence, the renewable energy sources (RES) integration and other load impacts on the grid were not discussed in detail, but notable references were included. The electric vehicle sales study (based on the Indian context) in a decentralized environment, as mentioned in Figure 1, shows a promising trend with a larger potential of EV industry in a decentralized market.

The main limitation of the research was the availability of the data during the pandemic times (COVID-19) for EV sales, and it was observed that the statistics are below average. The financial incentives for EV adoption with respect to other countries are less mentioned, as the topic is concentrated on the Indian context only. The contributing parameters like peak shaving, valley filling, and load levelling gains importance for grid stabilization during V2G, and sufficient research data on this is to be included for different EV models. The above issues can be considered as future scope or extensions of the review work for the research community.

The literature review is fairly unbiased and conclusive in its assessment that it will bring solutions and insight to the current barriers to the implementation of EV in the power grid. Integrating the nonlinear intermittent loads, such as renewable energy sources, to the grids and the potential benefits of the models discussed are worthy of further research. The advancement of technologies in the field of electric vehicles and decentralized markets has made it possible to make our lives easier and safer by using clean energy. We firmly believe that this evaluation has a positive impact on EV fleet integration and electric mobility.

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