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Review

A Review on Electric Vehicles for Holistic Robust Integration in Cities: History, Legislation, Meta-Analysis of Technology and Grid Impact

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Abstract: Electric vehicle technology is transitioning from mobility based on fossil fuel combustion to one based on vehicle electrification, in which the primary energy is increasingly renewable, and the generation of pollutants and CO_2 emissions is being reduced. This paper provides a tour of the key aspects of these systems, reviewing their most important historical, legislative, and grid impact topics. For this purpose, a literature review of publications up to 2022 is conducted. The last decade is the subject of a deeper analysis, shedding light on the essential characteristics of this technology and fundamentally focusing on its integration into electrical distribution networks. This work is carried out based on a review of a selection of articles written by authors worldwide who have researched these topics. We ordered and analyzed the temporal evolution of the defined categories, obtaining their research line direction. A meta-analysis of grid impact was also carried out, prompting clear conclusions about the state of the art and potential future works.

Keywords: electric vehicle; EV simulation; electrical grid; electrical shortage; power quality; EV integration in cities

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1. Introduction

The electric vehicle (EV) in all its modalities, whether hybrid, plugged-in, or battery [1], is presented as a feasible solution to the problems of resources, energy, and pollution management facing countries worldwide [2,3]. Multiple factors are accelerating its adoption by consumers and society, the most important causes of which have been studied for years and can be summarized as follows:

- Growing global concern about climate change and its effects on glacier melting [4], sea level increments, thermal variations and extreme precipitations attributed to global warming, specifically to greenhouse gas (GHG) emissions and the high CO_2 production associated with energy obtained through fossil fuel combustion. The reduction of GHG emissions caused by human activity, considered the main cause of rapidly advancing global warming [5], is a core priority. The International Energy Agency (IEA) has made several proposals aimed at limiting the increase in global temperature to two degrees Celsius by 2050 [6]. In this line, the transportation sector was the producer of 25% of GHG emissions in 2009. Since then, various initiatives have been implemented to reduce these gases by incorporating cleaner technologies in vehicles such as electrification, which emits less CO_2 than internal combustion engine vehicles (ICEV) when electricity comes from renewables or from the use of new fuels [7]. According to the European Environment Agency, 15% of GHG emissions are caused by the transportation sector, with this figure being 27% in the European Union (EU) [8,9]. In the case of the United States (US), this rate rises to 29%; thus, private and public organizations are working together to make it possible for all EVs to work with electricity from renewable sources [10,11]. In the US, the transportation and electricity sectors accounted for over 53% of GHG emissions in 2021 [12], with work on EV solutions showing the potential to improve these figures.

- A progressive increase in the costs of extracting crude oil and higher prices for consumers are among the reasons for the IEA warning of a decrease in gasoline and diesel production in the coming decades. Except in the US, where large investments have been made in fracking, oil companies are gradually ceasing to invest in new oil fields, and are diversifying them into other sectors such as electricity and renewables [13]. Thus, investment in clean energy by oil and gas companies doubled to around 20 billion USD by 2022, accounting for around 4% of upstream capital investment and 0.5% of net income [14].
- Although the enormous energy density and stability of fuels have favored their global use for more than a hundred years, the production of environmental pollutants from fossil fuel combustion for electrical or transportation purposes is increasing globally and becoming toxic at local levels in large cities, where the density of pollutants from tailpipes or factories is high and they remain immobile due to different weather conditions, causing episodes of low air quality and illnesses [15]. Approximately 90% of the world's citizens live in areas where the World Health Organisation's (WHO) air quality guidelines are exceeded. Cities produce about 78% of CO_2, and significant air pollutants affect the more than 50% of the world's population living in them [16].
- Greater global efficiency, rationalizing energy consumption, and the need for a new paradigm around the use of renewable resources is called for, along with changing the centralized energy production concept of the 20th century towards wider geographical distribution. This could include an increase in the penetration of Distributed Energy Resources (DER), in which Plug-in Electric Vehicles (PEV) can be included thanks to their capacity to provide stored electricity when necessary [17]. Further studies assessing the impact of penetration of DERs above 20%, reaching 40% and even 60%, are essential to anticipate their impact on the electricity grid [18].
- Due to different geopolitical strategies, many countries consider energy independence an important matter of state, raising the possibility of EVs providing future energy storage capacity when there are surpluses, transferring them to the country's own electrical system, and avoiding the need for importation when there are shortages [19,20]. As a reference, the authors of [21] quantified the global EV battery capacity available for grid storage through simulation, assuming a future level of EV battery deployment and other variables. They found a technical capacity of 32–62 terawatt-hours by 2050. Short-term grid storage needs could be met with EV user participation of between 12% and 43% as early as 2030 in most regions.

1.1. Problem Statement: EV Integration in Cities

The ambitious objectives for 2030 in the Climate and Energy Framework of the European Commission (EC) involve progressive substitution of ICEVs by PEVs and battery electric vehicles (BEV) over coming years, which will produce an increase in electricity consumption that must be addressed by a greater penetration of renewables [22].

Currently, several central and northern European countries have high EV penetration [23] and are suffering some of its consequences, which will be generalized to the rest of the countries as EV uptake increases. Grid imbalances may occur due to high demand for fast charging, harmonic injection, and a low power factor. Charging control must be improved through smart chargers to ensure that it is not done uncontrollably, and the aggregator figure will have to be consolidated by bringing together the interface between distributed system operators (DSO) and EV customers, all in coordination with management of renewables [24].

We conduct a review of interesting topics involving EVs, and especially the problem of EV integration into cities' electrical grids to avoid the described effects.

1.2. Motivation and Objective

This study was conducted because even though there is a large amount of scientific literature on EVs, few reviews include the main topics of this study and its associated complementary information. Hence, as a novelty, this paper includes a meta-analysis of the key issues related to EVs and their integration into electrical networks within the same document. We extract and classify the most important aspects of the research hitherto conducted, providing a baseline document and a starting point for future research.

The work has a triple objective: first, to fill a gap for a comprehensive review of many aspects that are associated with EV technology, including a historical, legislative, and literature review followed by extraction of key categories and their impact on the network; second, to define the baseline of EV research, indicating the state of the art in various defined areas related to this technology; third, to serve as a starting point for researchers and provide them with a numerical analysis to determine and distinguish the areas of greatest development and relevance despite the rapid changes taking place in this sector thanks to public–private collaboration. These areas are presented as those of paramount interest to the scientific community and where research resources should continue to be invested in order to chart a faster path to solving the significant engineering and socioeconomic problems associated with EVs.

1.3. Structure and Content

This study is divided into six sections. The first corresponds to the introduction, motivation, objectives, and structure. The second reviews the history of the EV, seeking to find the original publications or those closest to them along with the causes of the current situation, while understanding that EVs are as old as combustion engines. The Section 3 deals with the EU's legislative objectives for EVs in the coming years, referencing associated regulations and official data on EV uptake. The Section 4 analyses the number of public charging points installed worldwide and relates them to the current stock of EVs. On the other hand, it reviews and analyses the sales of electric buses and trucks, which are increasingly being integrated into cities and highways. The Section 5 is a methodological review of the existing literature on EVs up to 2022; we select relevant review studies, determine key categories, and then analyze their frequency of appearance and relative importance numerically and graphically throughout each year. In so doing, we perform an analysis of the relative importance of technical categories extracted from the articles based on the design of two ad hoc Key Performance Indicators (KPI). Based on these data, we conduct a meta-analysis of 32 selected EV review articles written in the last 11 years and extract an extensive energy and transport bibliography. The Section 6 addresses the impact of EVs in the electrical distribution network, showing the main aspects of research over the years that have not yet been completely solved for broad EV implementation in cities. The paper ends with a last section, which provides the main conclusions of the study.

2. Electric Vehicles: History and Evolution

The Hungarian inventor Anyos Jedlik István is credited with inventing a system in 1828 similar to a skateboard powered by an electric motor [25]. It was not until 1835 that the first electrically powered carriage-type vehicle, attributed to the English inventor Robert Anderson, was presented at an industry conference. It used a disposable battery powered by crude oil. The same year, Professor Sibrandus Stratingh (The Netherlands) together with his assistant Christopher Becker invented a three-wheeled EV [26]. In the same year, the American inventor Thomas Davenport invented the first model EVs. These were primitive vehicles that barely reached 12 km/h, and are considered the first EVs [27]. In 1837, the Scottish inventor Robert Davidson developed his own invented electric motor, performing tests on a model locomotive, and in 1841–1842 testing his motor in real vehicles [28].

In 1860, the first rechargeable lead–acid battery was invented by the French physicist Gaston Plante [29]. In 1882, William E. Ayrton and John Perry (England) developed a three-wheeled EV integrating two batteries, with the possibility of switching between them to control the vehicle's speed [30]. The first EV production is credited to Thomas Parker in 1884 [31], coming before Karl Benz and his Motorwagen petrol-powered vehicle in 1886 [32]. William Morrison (US) developed a six-passenger EV capable of reaching 23 km/h, in 1895 according to [33] or between 1887 and 1890 according to [34]. In 1897 the first electric taxi service was launched in London [35]. In 1898, Ferdinand Porsche invented an EV called the P1, which is considered the world's first hybrid EV, running on both electricity and gas [36]. In 1899, the EV 'La jamais contente' exceeded 100 km/h [37]. By the end of the 19th century, about 40% of vehicles in the US were battery-powered electric, with the rest powered by steam or gasoline. EVs were clean and comfortable, but batteries were inefficient and expensive, allowing for a distance of only a few kilometers and using a battery exchange model in which discharged batteries were removed and charged at service stations. Before the end of that century, Borland Electric's EV travelled 100 miles from Chicago to Milwaukee, charging the batteries overnight and repeating the reverse trip next day [38].

At the beginning of the 20th century, speed and range performance were similar in EVs and gasoline vehicles. In 1900, New York City came to have a fleet of electric taxis; between 1900 and 1910 there were 38% EVs, which worked without vibrations, although they had complex recharging systems. In comparison, 40% were steam cars, which had to wait almost 45 min to produce steam and constantly poured water, while 22% were powered by gasoline and were difficult to start, producing smoke and vibrations. There were also electric buses for public transportation; between 1909 and 1914, the Fritchle company sold almost 200 vehicles per year, guaranteeing 100 miles on a single charge. The sales peak was reached in 1912 [39], with EVs arousing so much interest that Henry Ford and Thomas Edison partnered to study opportunities around a possible low-cost EV in 1914. However, due to the cumbersome electrical charging systems and parallel discovery of large oil wells, the consequent cheaper gasoline as well as the development of better ICEVs, promoted by Henry Ford in 1908 with his Model T, tipped the balance towards thermal propellants. In 1912, Ford's mass production of vehicles meant that a gasoline car cost almost three times less than an EV [40]. In the same year, the first electric starter was invented by Charles Kettering, eliminating the cumbersome hand crank when driving ICEVs. This combination of factors led to EVs disappearing in the US over the following decade [41]. In Europe, Germany used EVs during the 1930–1940s. The EV concept was not rethought until the oil crisis in the 1970s, during which fuel costs increased dramatically [42]. In 1969–1970, General Motors developed the GM XP 512E, an EV prototype for cities [43].

In 1971, NASA used its Lunar Rover EV, with a range of 90 km and a speed of 13 km/h, for the Apollo 15 mission on the Moon's surface [39]. Another example of an EV from the same era was the 1974 Citicar [44]. In 1976, Chevrolet offered the Electrovette [45], and in the same year Volkswagen announced an Elektro-Golf, which had an external appearance similar to the original Golf GTi [46].

In 1979, Chrysler presented the ETV-1 Electric Car [47] and the Comuta EV [48]. All these models were limited in both top speed (72 km/h) and autonomy (64 km). In the 1980s, various environmental studies determined that one of the most important causes of pollution in large cities was ICEVs [49]. Electronics industries were called upon to improve battery capacity, with Nickel Metal Hydride (Ni-MH) batteries already on the market at the end of 1980s, and Lithium batteries with a much higher energy density very close to becoming a reality (1991) [50]. Due to the pollution levels reached in these years, the California Air Resources Board made the decision that by 1998 2% of the cars sold should not produce emissions and by 2003 this should increase to 10% [51].

In 1996, General Motors began full-scale manufacturing of the all-electric GM EV1. After thousands of units had been sold, the zero-emissions requirement was abruptly changed to low emissions, leading to General Motors pulling all EVs from the market. Toyota left some of its RAV-4 type models on the market. Officially, users were told that this action was due to the end of the useful life of the batteries [38]. The next step was the development of hybrid vehicles, which supported a gasoline engine using Ni-

MH batteries. In 1997, Toyota launched the Prius in Japan. In 2000, its distribution was expanded worldwide with great success, becoming the most sold hybrid model in the world [52]. In 2007, companies decided to manufacture EVs again due to increases in fuel prices. In 2008–2009, Tesla built a 100% EV Tesla Roaster with a lithium battery and 320 km of autonomy [53]. In 2010, a Daihatsu Mira was converted into an EV by the Japan Electric Vehicle Club, with the range exceeding 1003 km one charge [54]. In the same year, the EV 'Venturi Jamais Contente' reached a speed of 515 km/h [55]. At the same time, the 'Lekker Mobil' traveled 605 km from Munich to Berlin on a single charge of 115 kWh in real cooling/heating and traffic conditions [56].

The Chevrolet Volt extended-range electric vehicle (E-REV) was launched on the market in 2010. In this technology the power transmitted to the wheels is completely electrical and comes from two sources, the first stored in the vehicle batteries and the second produced by converting gasoline to electricity [57].

In 2011, the Nissan Leaf was declared the best car by the European Car of the Year awards [58].

The Opel Ampera, commercially launched in 2011, offered plug-in vehicle capabilities while being an E-REV [59]. In 2012 it was declared the best car in the European Car of the Year awards [60].

In 2013, the Drayson Racing Technologies B12/69EV reached 330 km/h [61]. In 2014, Nissan's ZEOD RC reached 300 km/h [62]. In the same year, the e-Golf was introduced on the market with a 24.2 kWh battery. In 2017, its capacity was increased to 35.8 kWh [63].

In 2017, the Rimac Concept reached 1088 hp, comparable to the famous Bugatti Veyron with 1001 hp [64]. In 2021, the 'e-Miles' was presented; designed for city driving, it is driven with a joystick, 90% of its parts are 3D printed, and it can be controlled via smartphone, with autonomous driving planned as well. [65]. In 2022, the high-end 'Lucid Air' was sold with a range of up to 520 miles, surpassing the 500-mile range anxiety barrier for customers regarding EVs compared to ICEVs [66]. Advances in 2023 and 2024 have been fundamentally dedicated to increasing autonomy, safety, and battery reliability [67], deploying a greater number of fast chargers accessible to citizens [68], and reducing the price of EVs to facilitate user uptake [69].

3. Current Objectives and Legislation for Successful European EV Penetration

According to Figure 1, global CO_2 emissions have increased continuously and considerably since the Industrial Revolution, reaching almost 38 Gt CO_2e in 2022 [70]. An important part of the scientific community considers that these emissions are responsible for global warming [5], and a significant proportion of these emissions come from the transport sector, which, based on fuel consumption, accounts for around 29% of global CO_2 emissions [71] and in the case of Europe 19.4% for the road transport sector [72].

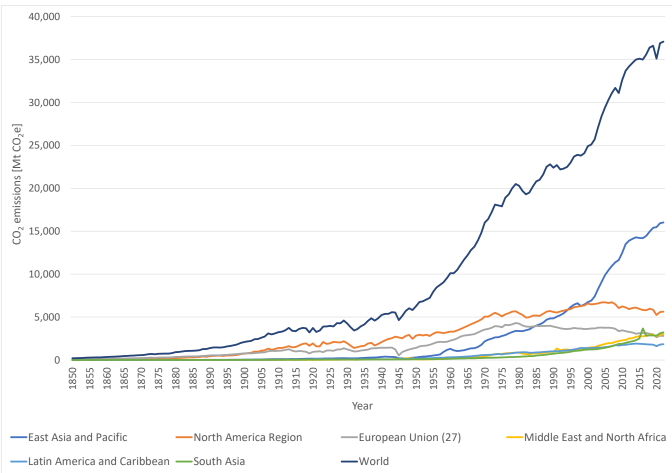

Figure 1. Global historical CO_2e emissions per year.

Based on the above reasons, this section studies the legislative evolution of ICEVs in Europe and the coexistence with current EV regulations towards a transition to net-zero emissions vehicles.

3.1. EU Legislation Background on ICEV Vehicles and Environmental Aspects

The EU has a long tradition of regulations for the reduction of pollutants in the environment. The first was included in Directive 70/220/EEC in 1970 [73], which was replaced by the 'Euro' regulations (Table 1), which include increasingly demanding requirements for reduction of toxic emissions such as CO, NO_x, HC, or particles from vehicles. These regulatory requirements have been implemented consecutively over the years through various European directives.

Table 1. Euro regulations, year of approval, and associated directives.

Name	Euro 1	Euro 2	Euro 3	Euro 4	Euro 5	Euro 6
Year	1992	1996	2000	2005	2009	2014
Directive	91/441/EEC [74]	94/12/EC [75]	98/69/EC [76]	2002/80/EC [77]	715/2007/EC [78]	459/2012/EC [79] 2016/646/EU [80]

Between Euro 2 and Euro 4, there emerged the "golden age" for diesel thermal combustion engines, with notable increases in power and efficiency reached due to the use of common rail and turbochargers [81]. Since 2001, the use of bio-fuels has been regulated to reduce emissions. New vehicles [82] based on hydrogen (fuel cells or combustion) and EVs have started to lead to a new paradigm shift in the transport sector.

Regarding CO_2 emissions, the EC instructed vehicle manufacturers to voluntarily reduce emissions; however, seeing that this measure had no effect [83], it was decided to present the legislative proposal COM(2007) 0019 to reduce CO_2 vehicle emissions at 120 g CO_2/km [84]. Thus, 2009 saw the approval of Regulation (EC) No 443/2009, the objective of which was to reach 95 g CO_2/km [85]. This regulation was finally replaced by the current one (as of the date of publication of this paper), Regulation (EU) 2019/631 [86], which will temporarily coexist with the new Euro 7 regulation to transition towards the zero net emissions goal in 2050, discussed below in Section 3.2.

3.2. Current European Legislation on EVs

The EU has set several temporary targets to eliminate polluting vehicles throughout its territory. In November 2018, the EU Vision for a climate-neutral Europe was defined to be consistent with the Paris Agreement, in which the commitment is to maintain the increase in global warming below 2 °C, and if possible no more than 1.5 °C [87].

The EU has set 2050 as the year in which it will achieve climate neutrality. This is a fundamental objective within the European Green Deal, an ambitious EU plan that aims for Europe to be the first climate-neutral continent by that year and in which the EU is to invest in technologies and research to support citizens to achieve that goal [88]. To begin this process, in December 2019 the European Council endorsed the objective of a climate-neutral EU by 2050 [89], submitting its long-term strategy to the United Nations Framework Convention on Climate Change (UNFCCC) in March of 2020 [90].

Another Green Deal objective is that of reducing net GHG emissions by at least 55% by 2030 compared to 1990 levels [91]. For these purposes the EC has developed the European Climate Law, which sets a legally binding target of net zero GHG by 2050 while addressing the necessary steps to reach both this target and the EU 2030 one [92]. Drawing on these two objectives, a set of proposals to revise and update EU legislation and include new initiatives to ensure that EU policies follow climate goals, which have been called 'Fit for 55', were submitted to the Council in July 2021. These comprise several policy areas, such as transport, environment, energy, and economic and financial affairs. In the transport case, the proposal introduces increased reduction targets of EU-wide CO_2 emissions for cars and vans by 2030 and sets a new target of 100% for 2035, meaning that from 2035 on all cars or vans sold on the market in the EU will be zero-emission [93]. In Brussels, a press release was published on 28 October 2022 indicating that the European Commission had reached an agreement "ensuring all new cars and vans registered in Europe will be zero-emission by 2035" [94].

It is important to emphasize that this regulation will apply to new ICEVs emitting CO_2. At the time of application, the regulations apply to cars and vans, not to trucks or motorcycles. In successive updates, these types of vehicles could change. EVs can also achieve the zero-emission requirement with BEV or hydrogen approaches that use 100% renewable electricity. Additionally, 'Fit for 55' plans for power generation include a milestone at which 40% of all energy produced in Europe in 2030 should come from renewables [93].

As can be seen in Figure 2, based on the European strategy described above and similar strategies in other regions of the world, the authors of [95] made projections for CO_2e emissions while distinguishing between 'advanced economies' and 'emerging economies and developing countries'. According to these estimates, the former will reach carbon neutrality four years earlier, although the latter will have to move much faster to achieve this goal.

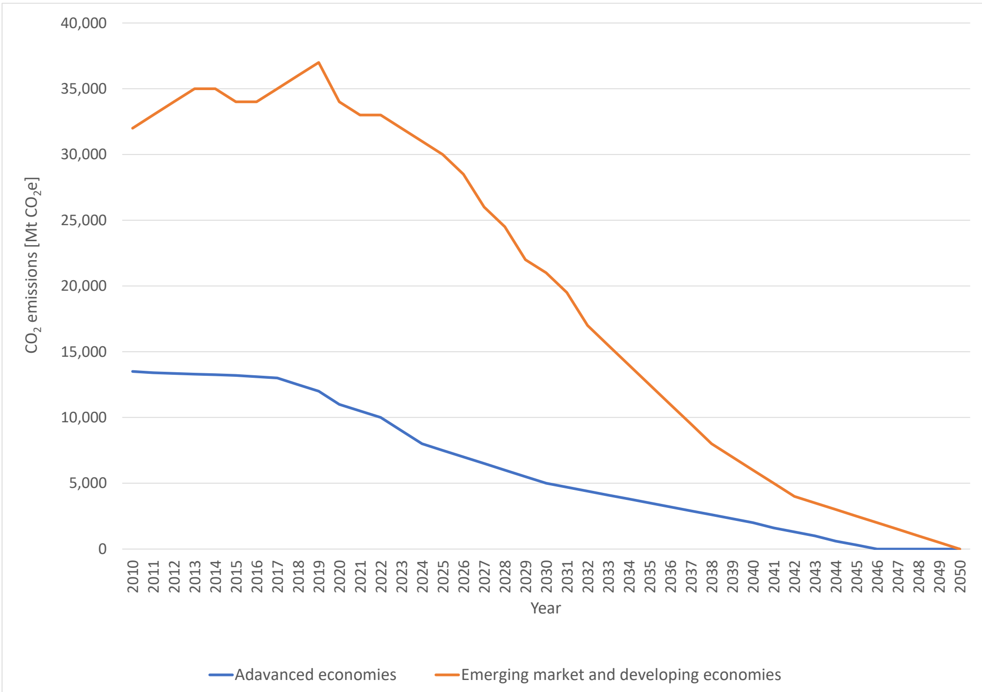

Figure 2. Global CO_2e forecasts per year.

Previous actions have had a great impact on the uptake of BEV and Plug-in Hybrid Electric Vehicles (PHEV) in the global (Figure 3) [96] and European (Figure 4) [97] marketplaces.

EV uptake is directly related to a wide range of charging points. For this purpose, taking Spain as an example, Royal Decree 29/2021, published at the end of 2021, obliges public and private entities in non-residential buildings with more than twenty parking lots to install a number of EV charging points proportional to the total parking lots as of 1 January 2023. Specifically, one charging point should be installed every 40 parking lots in companies and universities and one charging point every 20 parking lots in administrative and government buildings [98].

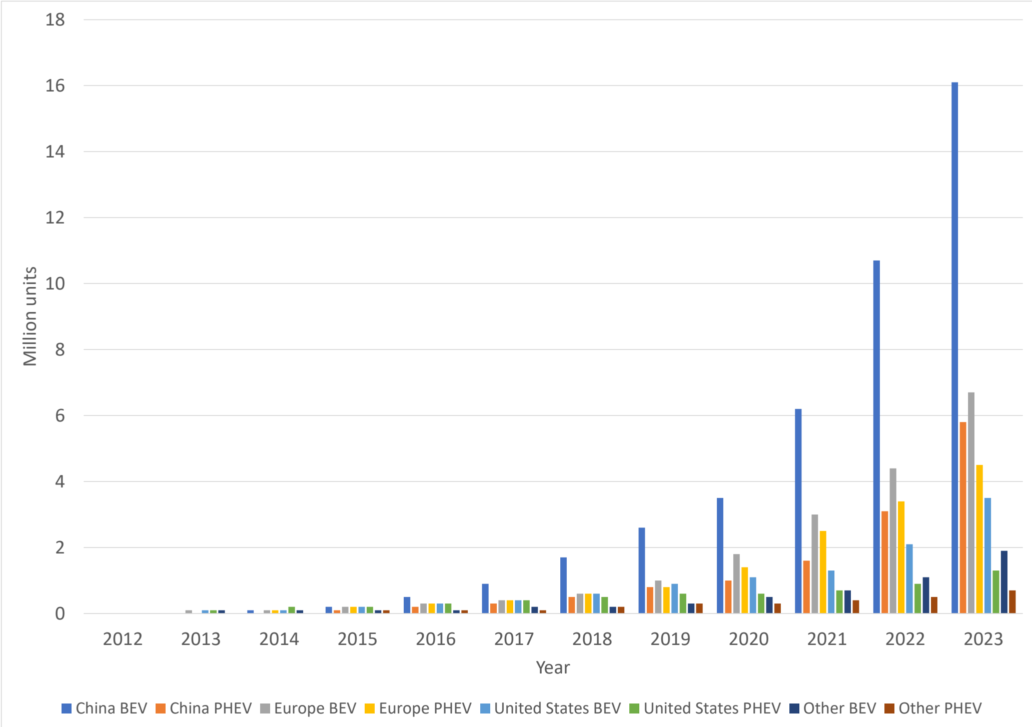

Figure 3. Evolution of global electric car stock.

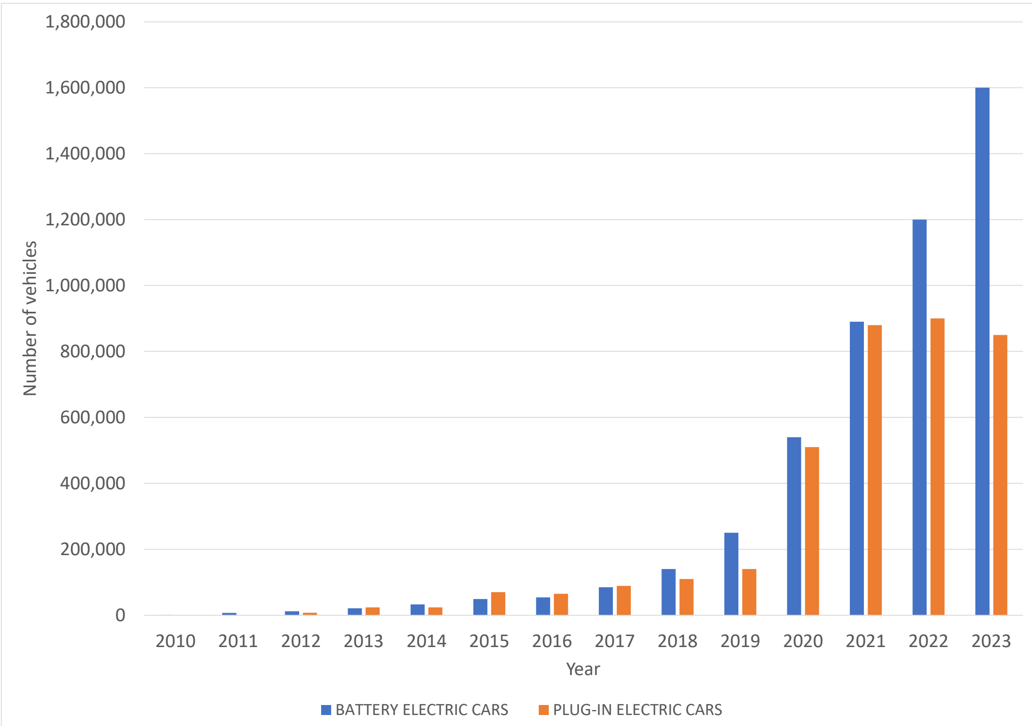

Figure 4. Evolution of new car registrations in Europe.

In November 2022, the Euro 7 proposal to reduce pollutant emissions from vehicles and improve air quality was approved. It will foreseeably come into force in 2025 for cars and vans and in 2027 for trucks and buses, and which will carry through until 2035, when new vehicles will be zero-emission. Euro 7 will consider tailpipe emissions and those due to brakes and tires, as well as battery life in the case of BEVs [99].

4. Charging Infrastructure and Other Types of EVs: Current State

This section focuses on the current state of public charging points and their relationship with the number of EVs. Other types of EVs are reviewed as well, such as Heavy EVs, as their acquisition by public entities and private companies is becoming more and more relevant.

4.1. EV Charging Infrastructure

It is estimated that there are almost ten times as many private chargers as public ones. These are usually located in the private car parks of EV users. Private charging points take advantage of cheaper hourly rates and tend to be located in less densely populated cities. Public chargers have a greater impact in cities with high population per unit area and low availability of private car parking [100]. Grid voltage on the consumption side may condition the installation of private charging points. In countries with a voltage of 220 V, overnight charging times of a few hours can be achieved, while in countries with a voltage of 100–120 V it is difficult to charge an EV in less than ten hours [101].

Increased availability of public charging points favors higher uptake of EVs by users [102]. Figures 5 and 6 present the number of publicly installed vehicle charging points per region by slow and fast chargers respectively, for 2015–2023 [103].

China stands out in the installation of public charging points compared to other regions, showing solid growth until 2023, followed by Europe. All other regions show sustained growth over the years. Fast chargers accounted over 35% of public charging stock at the end of 2023.

China leads the deployment of EV supply equipment, with around 60% of slow chargers and more than 85% of the world's fast chargers. Its target for 2030 is to achieve a full charging coverage in highways and cities. In relation to the European Union, the text of the alternative fuels infrastructure regulation agreed upon in 2023 requires public fast chargers every 60 km along the European Union's main transport corridors. This measure will allow 0.8 kW of publicly accessible chargers for each registered PHEV and 1.3 kW for each registered BEV [103].

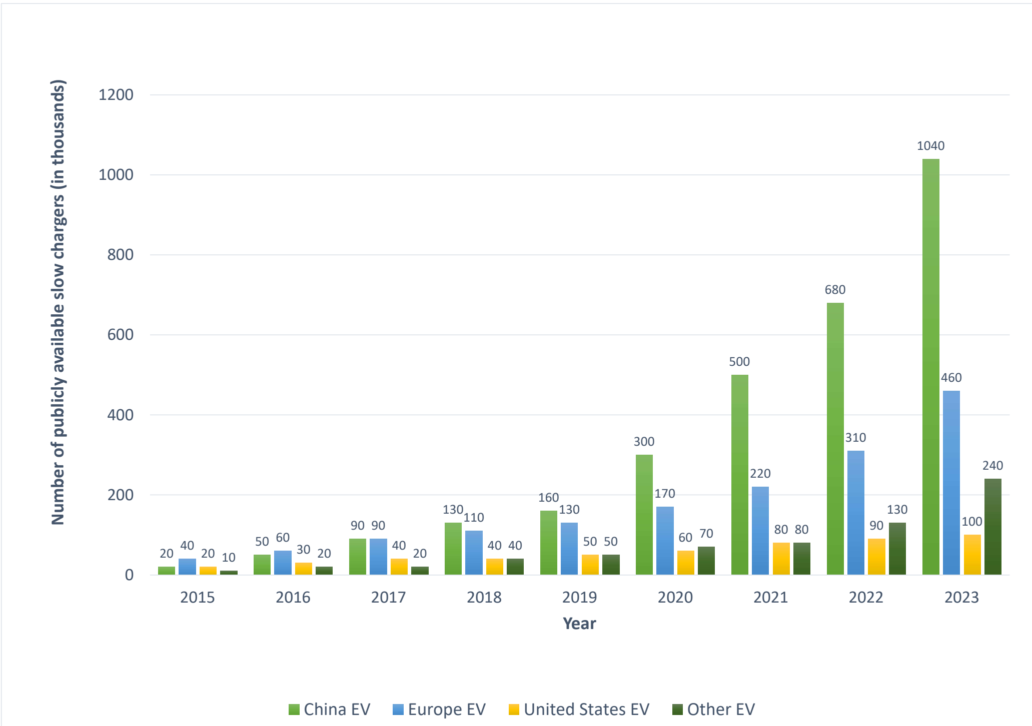

Figure 5. Available public slow chargers per region.

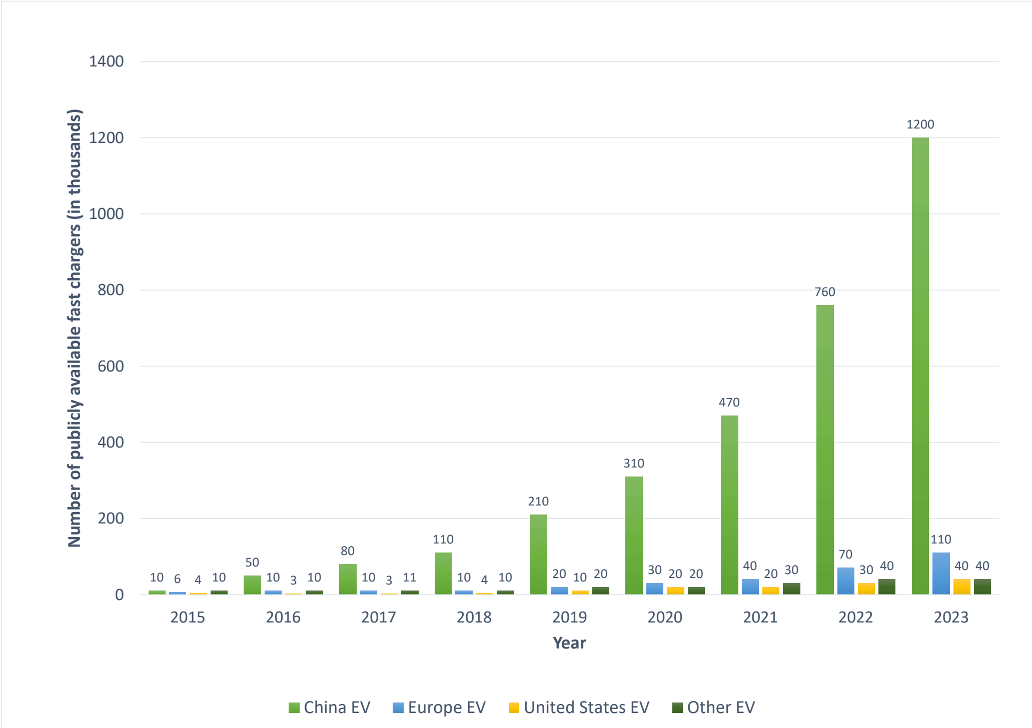

Figure 6. Available public fast chargers per region.

An analysis can then be carried out to assess the temporal evolution of the number of vehicles per public charger, both slow and fast; to this end, the data extracted from Figure 3 for PHEVs and BEVs are unified into a single value by region and year, and divided by the number of chargers for the cases represented in Figures 5 and 6. The results can be seen in Figures 7 and 8.

Figure 7 shows the fluctuations corresponding to the number of EVs per public slow charger. China has a stable curve with a low average value, indicating a good match between new vehicle sales and electric infrastructure deployment. As both factors vary appreciably from year to year, while their stability is continuous, it can be concluded that there is a consolidated strategy in EV production and electric infrastructure deployment. The region 'Other EV', for which the variation in both factors is very small (Figures 3 and 5), indicates that the market is still in its infancy, which is the reason for the apparent stability. In the case of Europe, limited and stable behavior can be observed, with both factors growing in step with each other. Finally, the US still shows non-stable behavior that depends on the increased production of EVs in certain years and increased installation of charging points in others. It is expected that these regional values will be very stable from 2030 onwards due to the supranational plans that are being implemented to replace ICEVs and the deployment of charging points in these regions.

Figure 8 shows similar behavior to the previous case for fast charging points. As this is a more advanced technology, the differences between regions is magnified. It can be observed that China has reached a practically constant ratio between EVs and fast chargers after 2016, with the small value indicating high availability of public fast charging service.

In the Other EV category, despite the stability of the graph, gradual growth can be observed. This will potentially increase in the coming years with the surge in EV sales. Europe is escalating this ratio in an oscillating albeit controlled way, while continuing to increase the number of EVs and fast charging points. Finally, in the case of the US, the deployment of fast charging points has increased from 2019, reaching ratios similar to those in Europe, though not yet in terms of the number of EVs sold or the deployment of fast chargers.

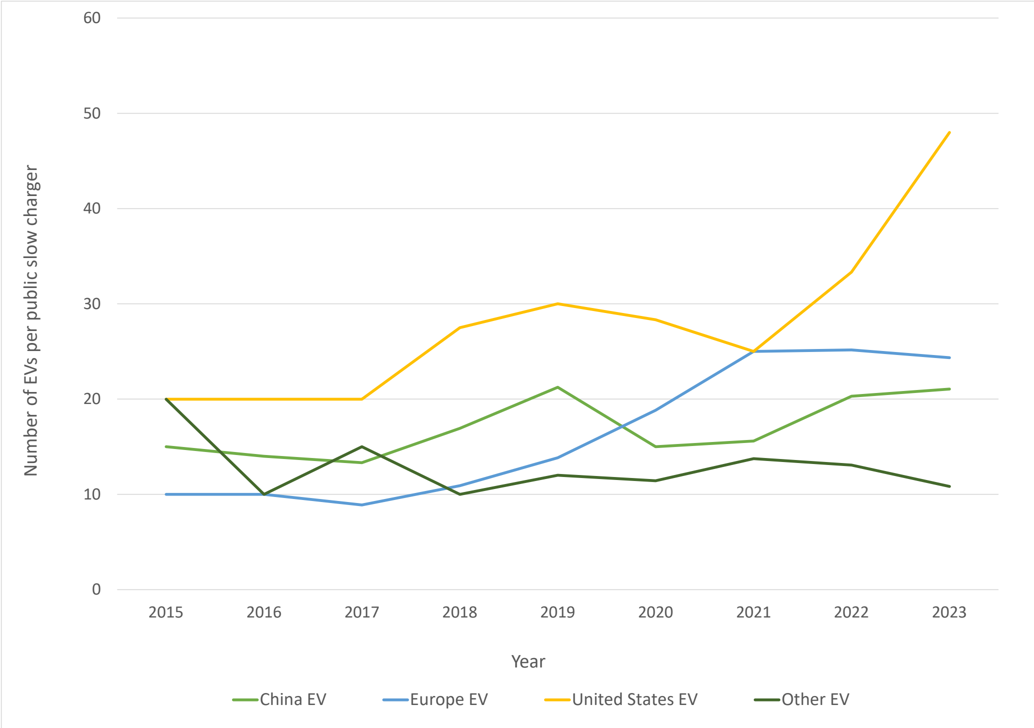

Figure 7. Number of EVs per available public slow charger by region.

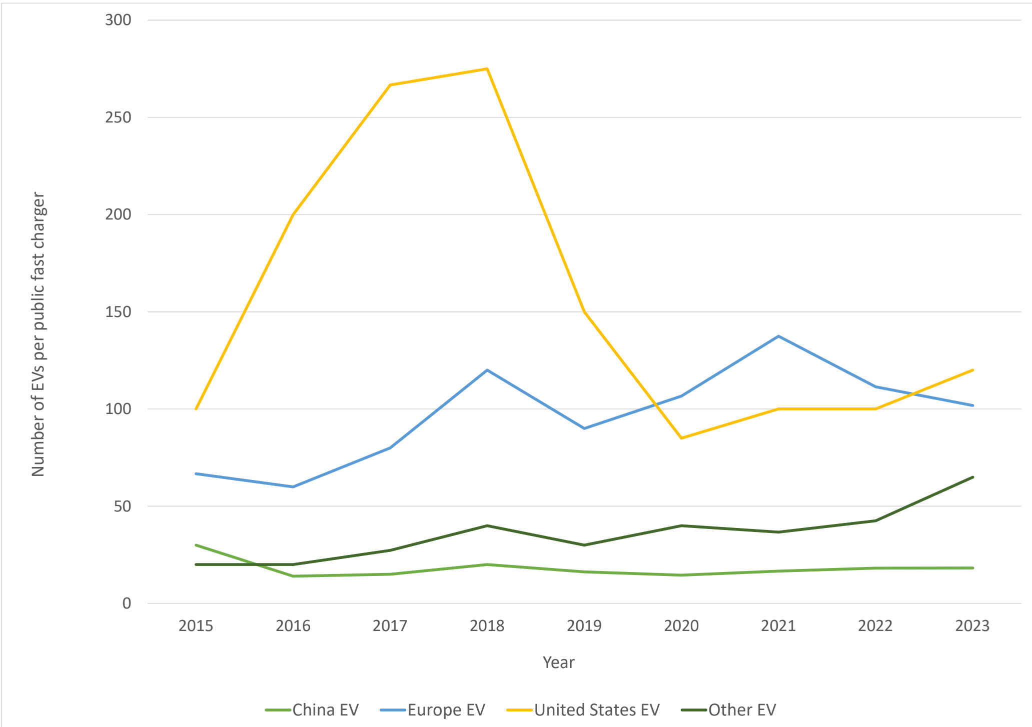

Figure 8. Number of EVs per available public fast charger by region.

4.2. Heavy EVs

This subsection deals with heavy EVs, which for the purposes of this study are those other than passenger cars. Specifically, electric buses for travelers and electric trucks for freight transport are discussed.

4.2.1. Electric Buses

Figure 9 represents the sales of electric buses in different regions of the world between 2015 and 2023. It can be seen that the largest producer of these vehicles is China, followed by Other, Europe, and the USA. Since 2018, sales of these vehicles have started to grow moderately but continuously. There are various reasons for this, including the low penetration of these vehicles in large markets such as Korea and the USA. On the other hand, sales of these products are very limited in emerging and developing countries [103].

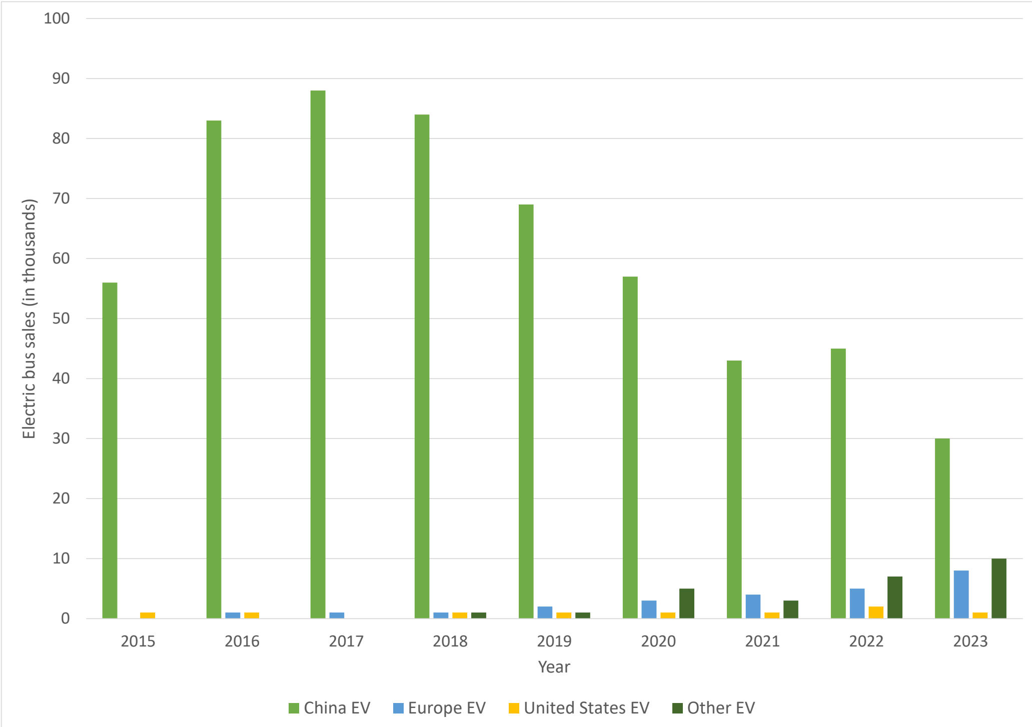

Figure 9. Number of electric bus sales per year by region.

4.2.2. Electric Trucks for Freight Transport

In Figure 10, it can be seen that after fluctuating between 2015 and 2020, sales of electric trucks have increased each year up to 2023, with China leading the way in production of these vehicles. From 2021 onwards, Europe picks up the pace, selling more units, a behavior that can be explained by the EU's emission reduction targets of 90% CO_2 by 2040 for this type of vehicle [103].

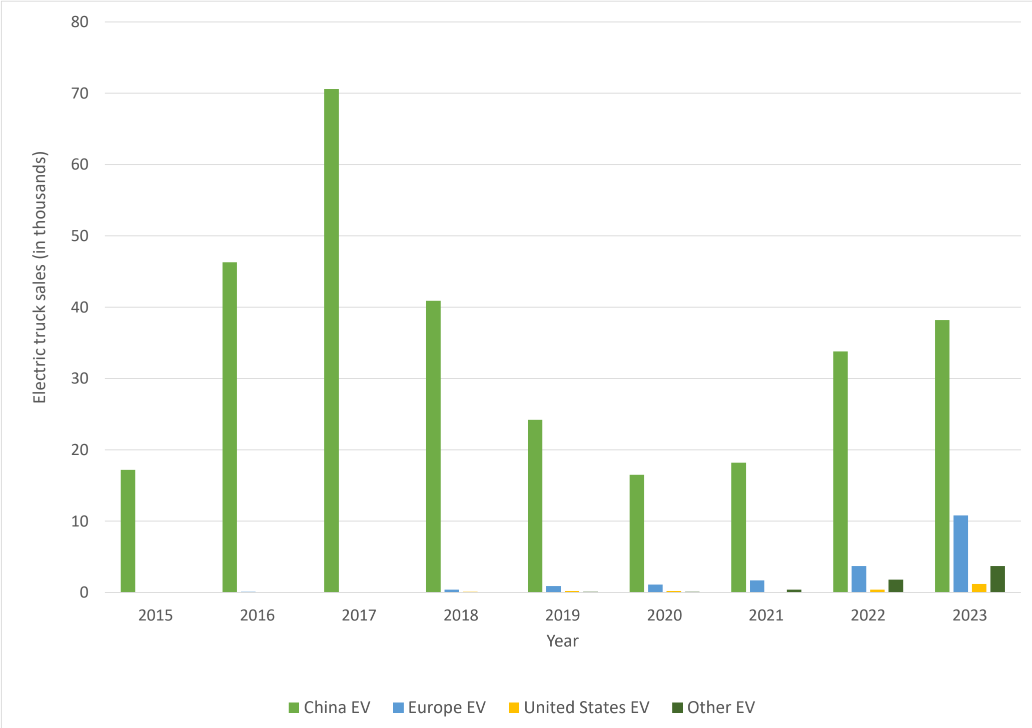

Figure 10. Number of electric truck sales per year and region.

5. Methodological Review of Existing Literature

A main aim of this study is to carry out a chronological analysis of review articles related to the incorporation of EVs in distribution networks and the integration of Renewable Energy Sources (RES) and management of these systems over time. Review articles include a summary of the most important advances at the time they were written; a meta-analysis of these will enable us to understand the evolution of technological research on the subject we are dealing with and make extrapolations for the future.

To conduct the study, we worked with the IEEE Xplore, Scopus, Google Scholar, and Web of Science databases, planning different levels of searches. In the first place, the search period was determined, finding 1973 as the first year in which an EV article was published within what we consider the modern era, as opposed to the historical context discussed in Section 2. An iterative searching process was carried out including more terms and conditions, revealing a few articles containing the characteristics that we sought. In a first analysis (Figure 11), we evaluated the literary production containing "electric vehicle and electrical networks" terms, along with their possible variations in the search rules, for any type of scientific article, finding the first references in 1976 (series in blue). A part of this methodology is based on [104]. The next analysis added the "renewables" term to the previous search, obtaining the yellow series.

Regarding the blue series, two periods were detected: the first up to 2007, with scant scientific output, and another from 2007 onwards showing continuously growth until 2022. Looking at the chart carefully, as many as eight different trend changes can be observed:

1973–1975: There are no scientific 'EV' plus 'electrical networks' publications.

1976–1990: Small EV models were introduced into the market, with limited benefits because they used lead–acid batteries with low charge density. In this period, the effects on the power factor of the first EV chargers, which generated harmonics in the distribution network, began to be investigated [105].

1991–1996: These were the years in which the GM EV1 was launched and the use of Ni-MH batteries with higher capacities and charge cycles became more widespread. There was interest studying the issue of charging peaks when many EVs were present in distribution networks, with some authors concluding that EV penetration greater than 20% could not be achieved due to the long battery charging time of 12 h [106].

1997–2005: The launch and worldwide distribution of the Toyota Prius meant that Hybrid Electric Vehicles (HEV) began to take center stage. The study of BEVs and their impact on networks continued to advance, seeking to determine the impacts of different levels of EV penetration [107] and fast chargers [108] as well as how transformers are affected by EVs [109].

2006–2010: Fuel price increases and the launch of the Li-ion battery Toyota Roaster BEV boosted the interest of researchers in EVs. The Vehicle-to-Grid (V2G) paradigm was defined for the first time [110], which triggered profuse research on this subject. By the end of this period, almost all of the "classic" EV problems had been described.

2011–2016: BEVs along with hydrogen combustion engines and fuel cells, were considered a real solution for gradually replacing fossil fuel-powered combustion engines. Studies carried out at this point included "classic" EV problems, optimization of recharging [111], cancellation of harmonics, and potential positive effects of EVs on the network [112].

2017–2020: Topics related to network voltage stability through the automatic variation of battery charge current level were researched [113] as well as the effects on EV generation and consumption in real time [114]. The IEA report addressed EV results on charging at low demand times, the variable use of RES for reliability, and Demand-Side Response (DSR) aspects as a means of EV charging control [115].

2021–2022: An acceleration in scientific output is observed during this period. Specific issues regarding how networks are affected by alternating EV charges with high-capacity batteries emerge as a new concept to be addressed [116]. On the other hand, research on aspects such as the characterization of several EVs and their supraharmonic emissions [117], which in previous years were not easy to predict, could be derived from observations of real technologies integrated at scale.

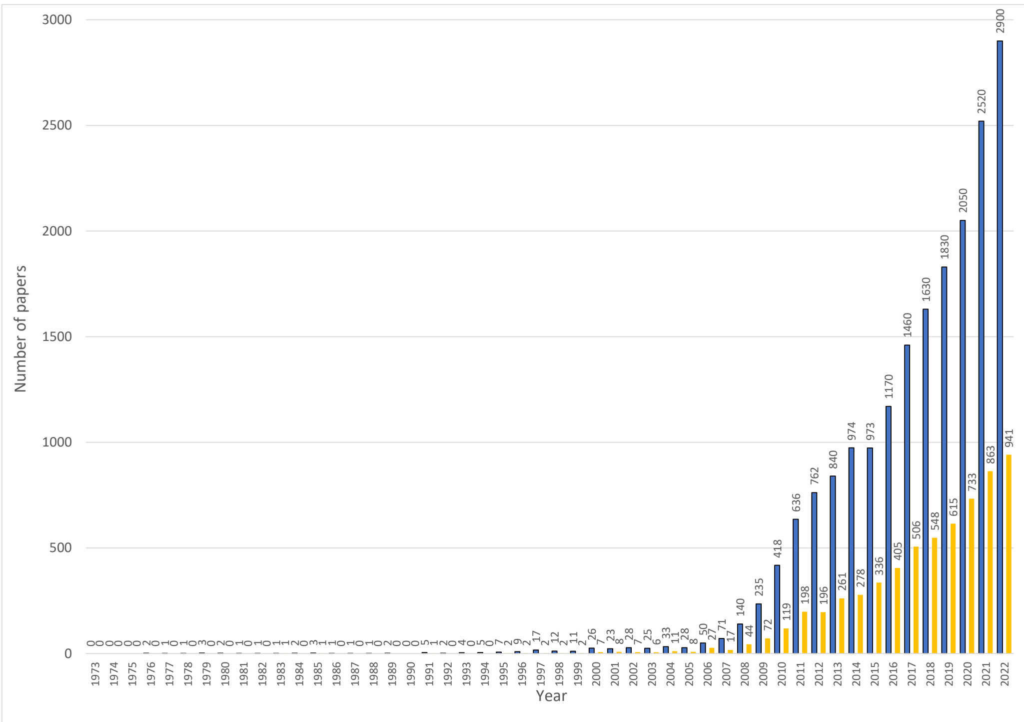

Figure 11. Chronological publication analysis of 'electric vehicle' plus 'electrical networks' (series in blue); the series in yellow includes the same terms plus 'renewables'.

Regarding the yellow series, a logical reduction in the number of articles is observed, with gradual growth from 2006 until 2022, indicating that the three search terms have generated continually increasing interest in the scientific community.

Considering only review articles that already include consolidated progress from previous years in different aspects, the two series are shown in Figure 12.

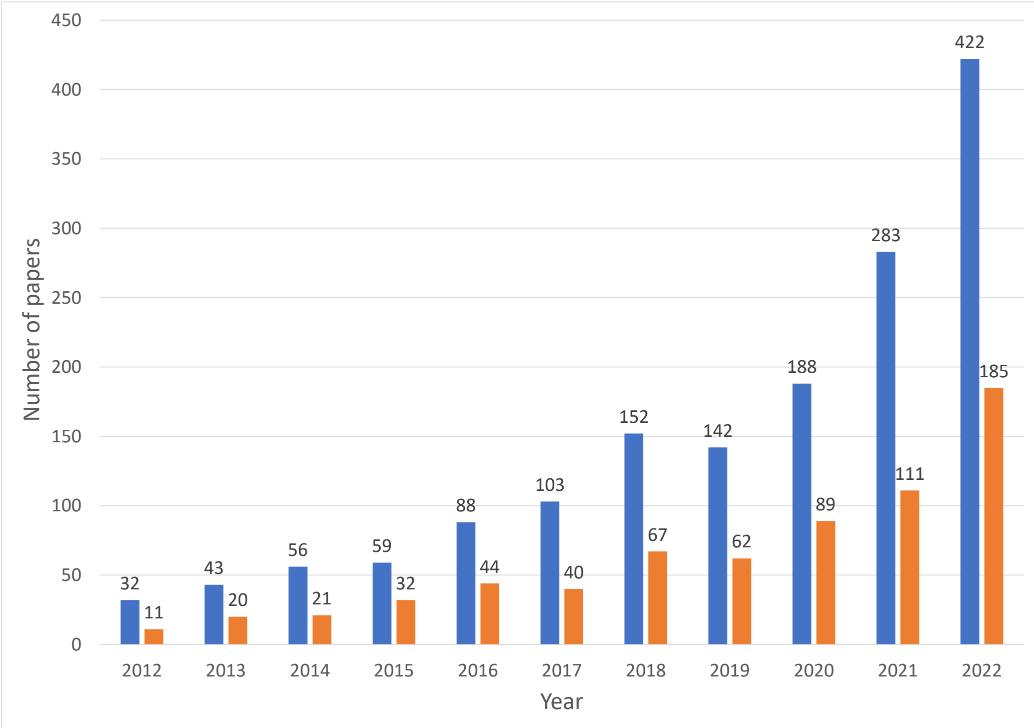

Figure 12. Chronological publication analysis of 'electric vehicle' plus 'electrical networks' plus 'review' papers (series in blue). The series in orange shows the same terms plus 'renewables' for the period from 2012 to 2022.

Both bar graphs correspond to Series 1 and 2 seen previously, but with only review articles included. For this study, we only selected the articles corresponding to the orange series, as it incorporates the criteria we searched for and the number of studies is manageable, allowing for selection of only the most appropriate. Our meta-analysis covered 2012 to 2022, comprising the years of greatest EV development and progression.

Up to four articles per year were selected proportionally to the number of articles published (except the first years), as indicated in Table 2, based on quality, the content of the publications, the number of citations, and a reasonable geographical distribution reflecting the global research diversity, as can be seen from Tables A1–A6 and in Figure 13. The countries of origin of the selected review papers were USA, Canada, Colombia, China, Australia, India, Pakistan, Malaysia, Denmark, France, Sweden, Germany, Italy, and Spain representing an even distribution of knowledge from across the world.

Regarding the fields in which the authors of the review articles worked, 96.88% were researchers at their respective universities, while the remaining 3.12% worked in the electrical industry.

Table 2. Number of review articles selected per year.

Year	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	Total
Number of articles	1	2	3	3	3	3	3	4	4	3	3	32

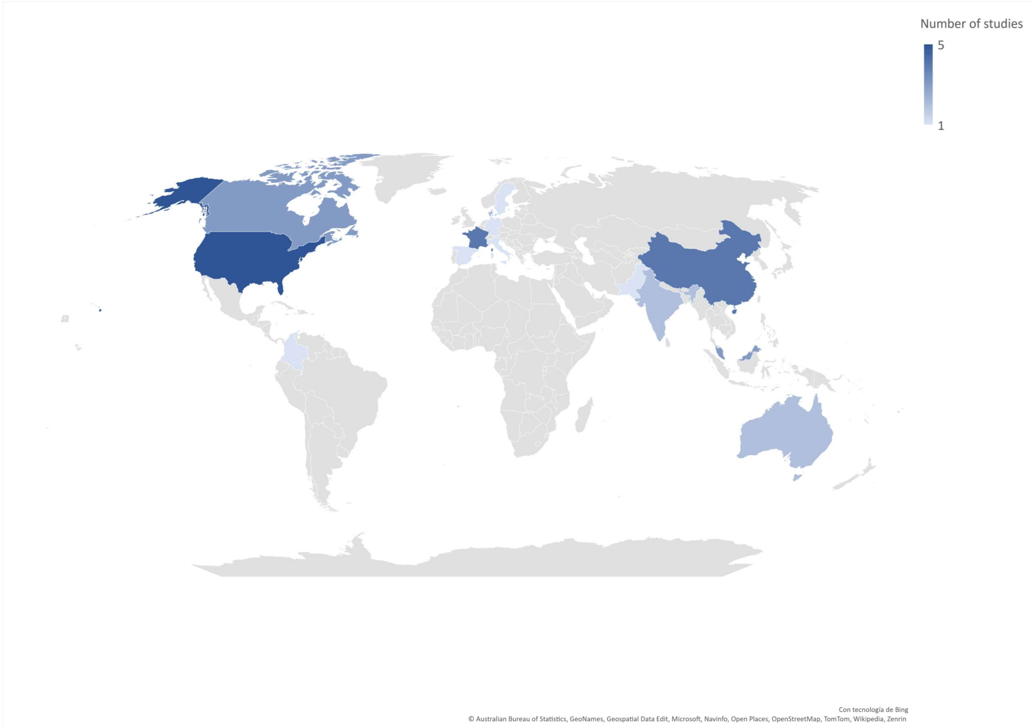

Figure 13. Geographical distribution of review articles; darker colors indicate a larger number of papers.

In this review, eight main categories were studied over time, as in our view they include the essential aspects of both EVs and their integration into electrical networks and RES effects. Certain categories were subdivided into other subcategories to collect concepts and details that may be interesting to follow and research. We show these elements in Table 3, with the same colors subsequently used in the other graphs for data analysis.

Table 3. Selected categories and corresponding acronyms.

Category	Acronym
Simulations	S
Technology	T
Grid Impact	GI
Cost, energy and pollution savings using EV instead ICEV	C&S
Emission reduction management in relation to ICEV without RES	E
Smart Grid technologies	SG
EV and Wind Power	WP
EV and Solar Power	SP

Simulations: This category provides tools to predict future effects by simulating scenarios of interest, anticipating the best technical and economic solutions. Within it, four subcategories are considered: long term, which includes simulations to anticipate effects from several days to years; short term, for simulations ranging from milliseconds to hours or even a day; optimization algorithms, for the type of simulations that find optimal points of energy consumption, percentage of RES to include, and cost reduction strategies on the production and consumer's side; and PHEV/EV penetration and electric system capacity. Simulations are carried out to determine how many EVs the electrical distribution system can accept according to the restrictions studied in each use case.

Technology: Includes technological aspects of EVs and their integration into the electrical network. Seven subcategories are considered: battery technology remanufacturing and recycling, which refers to batteries in general along with chemistry, autonomy, types, and recycling; chargers/charging stations, including research to make the charging network viable or to deal with speed, location, or harmonics aspects; fast chargers and related problems and solutions; wireless chargers and research into these systems; Vehicle-to-Grid/Home/Vehicle (V2GHV), Vehicle–Grid Integration (VGI), and Grid-to-Vehicle (G2V) research, which includes the aspects of bidirectional electricity transfer between the grid and EVs; electric motors, including constructive aspects; and finally electronics, including advances in power electronics related to inverters, converters, and control systems for the improvement of EVs.

Grid Impact: This includes papers that refer to the impact of EVs on the electricity grid. Five subcategories were selected: smart charging/charge management and location, including general design aspects of smart charger installation, topologies, and their best location; transformer congestion and line deterioration in distribution networks, including papers on power transformers and their potential loss of life due to the effects of EV connections; quality of electrical signal, which includes research related to this variable when EVs are incorporated into the network; stability of power systems and grids under increasing EV penetration; and demand response (DR), which collects knowledge related to interactions between users and their demand responses for different distributor strategies.

Cost, energy, and pollution savings of using EV instead of ICEVs: Several articles provide estimations or justifications around EVs in terms of energy savings and avoiding pollutants (NO_x) and particles (HC) compared to traditional ICEVs.

Emission reduction management in relation to ICEV without RES: This category includes articles in which conclusions are drawn about the reduction of CO_2 emissions from incorporating EVs in cases without integration of RES in the system. Aspects such as better balancing of charging and storage capacity on the part of EVs in relation to ICEVs are included as well.

Smart Grid technologies: Articles referring to communication technologies, control strategies, and management of networks are included in this category.

EV and Wind Power: Contains five subcategories involving studies on the influence of RES and the relationship with EV penetration: increments in EV and wind power facilities, relating to both systems and their necessary joint growth; shortage and quality of production (RES penetration issues), determining classic challenges of RES penetration in grids and how EVs can help; energy efficiency vs. fossil fuel consumption, including studies analyzing EV energy efficiency with wind power models in comparison to fossil fuel vehicles; emission reduction management, including studies of how emissions are reduced by wind power usage; and operational cost management (users and companies), including economic studies on better management of EVs and wind power together.

EV and Solar Power: Includes studies considering the influence of SP and its relationship with EV penetration. Six subcategories are included, the first five being equivalent to those of the previous WP category but for photovoltaic energy (PV): increments in EV and solar facilities; shortages and quality of production (RES penetration issues); energy efficiency vs. fossil fuel consumption; emissions reduction management; operational cost management (users and companies); and an additional sixth category, energy management among EVs, PV, and HVAC, which considers studies incorporating both categories plus heat, ventilation, and air conditioning (HVAC) systems in buildings.

Our analysis of these categories is shown in Table 4, with a tick indicating when a topic is discussed in the corresponding study.

Table 4. Analysis of categories and subcategories, with a tick indicating when a topic is researched in the corresponding study.

	Integration of EV in Distribution Grids																															
Study	**S1**	**S2**	**S3**	**S4**	**S5**	**S6**	**S7**	**S8**	**S9**	**S10**	**S11**	**S12**	**S13**	**S14**	**S15**	**S16**	**S17**	**S18**	**S19**	**S20**	**S21**	**S22**	**S23**	**S24**	**S25**	**S26**	**S27**	**S28**	**S29**	**S30**	**S31**	**S32**
Year	**2012**	**2013**	**2013**	**2014**	**2014**	**2014**	**2015**	**2015**	**2015**	**2016**	**2016**	**2016**	**2017**	**2017**	**2017**	**2018**	**2018**	**2018**	**2019**	**2019**	**2019**	**2019**	**2020**	**2020**	**2020**	**2020**	**2021**	**2021**	**2021**	**2022**	**2022**	**2022**
Simulations	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓		✓	✓			✓	✓	✓		✓		✓	✓	✓	✓	✓		✓	✓	✓	✓	
Long term		✓		✓			✓															✓								✓		
Short term	✓			✓																		✓								✓		
Optimization algorithms			✓			✓	✓		✓	✓		✓	✓			✓	✓	✓		✓		✓	✓	✓	✓	✓		✓		✓	✓	
PHEV/EV penetration and electric system capacity	✓		✓	✓	✓	✓		✓		✓			✓				✓	✓					✓		✓				✓	✓		
Technology	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓			✓		✓	✓	✓				✓	✓	✓	✓	✓	✓
Battery technology, remanufacturing and recycling	✓		✓	✓				✓	✓	✓	✓	✓	✓		✓	✓			✓		✓						✓	✓				✓
Chargers/Charging stations	✓			✓	✓		✓	✓	✓	✓	✓		✓	✓					✓								✓		✓	✓	✓	✓
Fast chargers														✓					✓								✓		✓	✓	✓	✓
Wireless chargers														✓					✓													✓
V2GHV or VGI or G2V	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓		✓	✓	✓	✓	✓			✓			✓	✓					✓	✓		✓	✓
Electric motor				✓			✓		✓																							
Electronics (inverters, converters and control systems)	✓		✓	✓				✓	✓		✓	✓	✓	✓					✓								✓		✓	✓		✓
Grid Impact	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓		✓	✓	✓	✓		✓	✓	✓	✓		✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Smart charging/charge management and location	✓	✓	✓		✓	✓	✓	✓		✓		✓	✓	✓	✓		✓	✓	✓	✓		✓	✓	✓	✓	✓		✓		✓	✓	✓
Transformer congestion and line deterioration	✓	✓	✓		✓	✓	✓	✓	✓			✓	✓		✓				✓				✓	✓				✓	✓	✓		
Quality of electrical signal	✓		✓	✓	✓			✓	✓			✓	✓										✓	✓			✓	✓	✓	✓		✓
Stability of power systems/grid	✓		✓	✓	✓		✓	✓	✓	✓		✓	✓						✓			✓	✓	✓				✓		✓	✓	✓
Demand Response (DR)			✓		✓	✓			✓														✓	✓	✓	✓				✓	✓	
Cost, energy and pollution savings using EV instead ICEV	✓	✓						✓	✓								✓				✓										✓	
Emission reduction management in relation to ICEV without RES	✓		✓				✓	✓	✓						✓		✓				✓											
Smart Grid technologies	✓			✓	✓	✓	✓	✓	✓	✓		✓	✓	✓											✓	✓		✓	✓	✓		✓
EV and Wind Power	✓	✓	✓				✓	✓	✓	✓		✓	✓								✓			✓				✓				
Increments in EV and wind power facilities	✓	✓	✓				✓	✓		✓			✓																			
Shortage and quality of production (RES penetration issues)	✓	✓	✓				✓	✓		✓		✓												✓				✓				
Energy efficiency vs. fossil consumption	✓						✓	✓		✓																						
Emission reduction management	✓						✓	✓	✓	✓		✓									✓											
Operational cost management (users and companies)	✓	✓	✓				✓	✓	✓																							
EV and Solar Power	✓	✓	✓				✓	✓	✓	✓	✓	✓	✓				✓	✓			✓	✓	✓	✓	✓	✓		✓		✓		
Increments in EV and solar facilities	✓	✓	✓				✓	✓		✓	✓		✓				✓	✓					✓		✓	✓		✓		✓		
Shortage and quality of production (RES penetration issues)	✓		✓				✓	✓		✓	✓	✓					✓	✓				✓	✓	✓	✓			✓		✓		
Energy efficiency vs. fossil consumption	✓	✓					✓	✓									✓	✓				✓	✓									
Emission reduction management	✓						✓	✓	✓	✓		✓					✓	✓			✓		✓									
Operational cost management (users and companies)	✓	✓	✓				✓	✓	✓								✓	✓				✓			✓	✓		✓				
Energy management among EV, PV and HVAC		✓															✓	✓				✓			✓							

Based on Table 4, a study of the timeline was carried out to observe the evolution of the different categories related to EVs and study the scientific community's interest in each of them. For each year, the percentages of total studies in each category are compared in Figure 14.

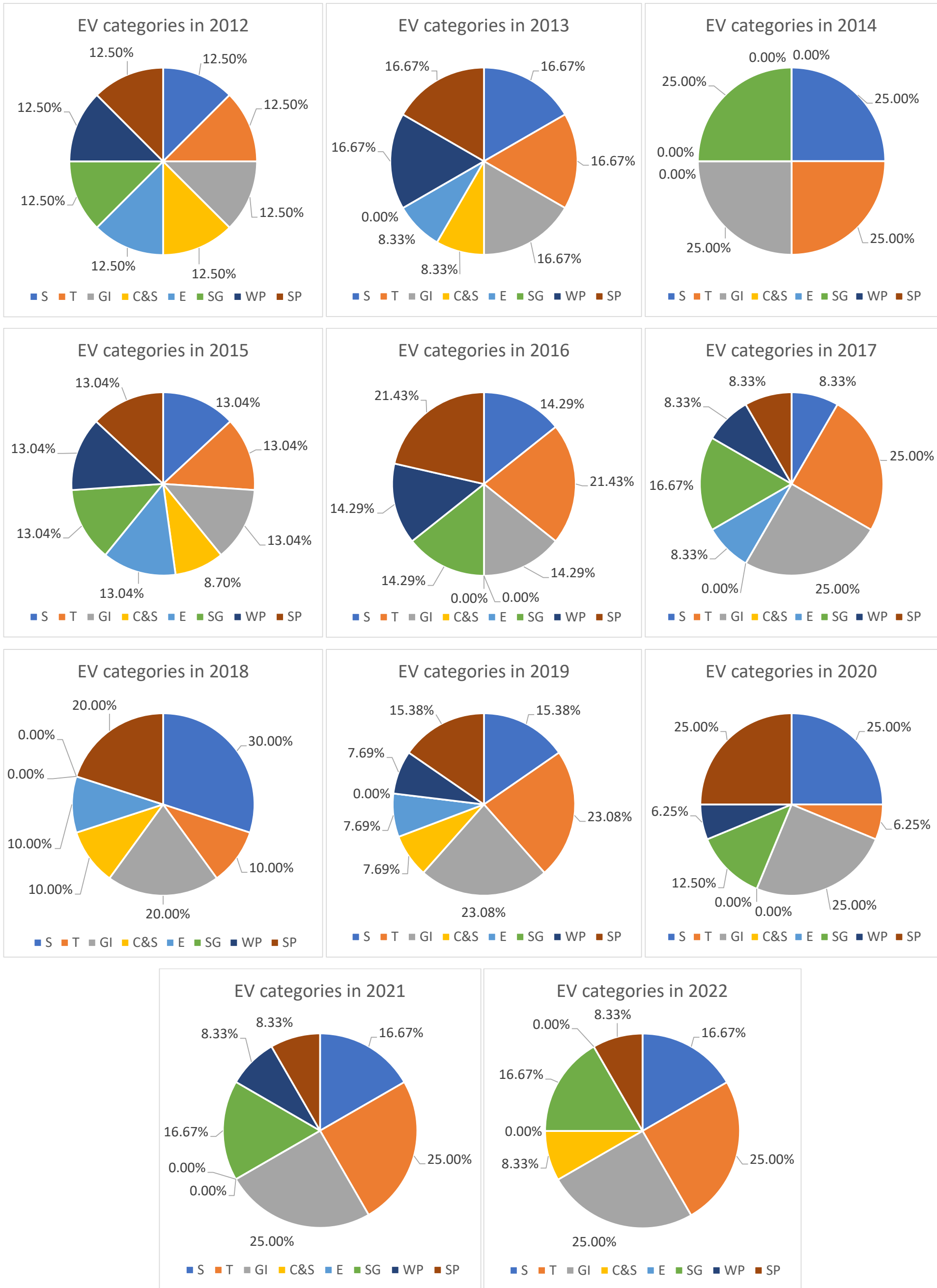

Figure 14. Evolution of EV research from 2012 to 2022 according to the selected categories.

S appears every year in the selected articles, showing variations between 8.33% and 30.00% (mean: μ_S = 17.60%, standard deviation: σ_S = 6.44%) with respect to those ones studied. Its behavior is oscillating, although present throughout the period. It can be concluded that the use of simulation for EV research in electrical networks has been persistent and continues to be so. Predicting system behaviors allows for their evolution and optimization, and is key to obtaining valuable results.

T is present every year, varying between 6.25% and 25.00% (μ_T = 18.45% and σ_T = 7.00%) with oscillating behavior, although present throughout the period. The technological topics change during the years of study, with greater focus on electric motor technology in the first years and power electronics (inverters, converters, and control systems) for elimination of harmonics and better fast charger implementation in the later years.

GI is present throughout the period, oscillating between 12.50% and 25.00% (μ_{GI} = 20.42% and σ_{GI} = 5.30%). All studies refer to this topic, whether in a simply introductory way or by developing it in more depth. The increase in network EV penetration and associated problems is a subject on which the scientific community agrees, appearing in many studies. The low level of σ_{GI} confirms this fact, although the base search for articles was focused on this topic.

C&S presents intermittent behavior, with a range of values between 0% and 12.50% ($\mu_{C\&S}$ = 5.05% and $\sigma_{C\&S}$ = 4.99%). This topic can be segregated into two sets of research: studies seeking to justify the superiority of EVs compared to ICEVs in terms of energy and pollution in cases where the primary energy is not renewable; and studies in which it is assumed that EVs will eventually be used with a renewable mix.

E shows intermittent behavior, and does not appear every year. The range of values is between 0% and 13.04% (μ_E = 5.45% and σ_E = 5.46%). Again, two types of research can be identified: studies investigating EVs as a solution to reduce emissions by themselves (i.e., without adding RES), and those directly focused on other aspects while assuming a future renewable mix.

SG oscillates between 0% and 25.00% (μ_{SG} = 11.58% and σ_{SG} = 8.19%). This category is closely related to telecommunications and the Internet of Things (IoT) systems, and frequently involves the management of smart grids; therefore, the presence of high EV penetration shows important dependency on the GI category. Depending on the topics researched in each year's reviews, authors may not specifically indicate this; nevertheless, any grid impact would be impossible without smart grids.

WP oscillates between 0% and 16.67% (μ_{WP} = 7.92% and σ_{WP} = 5.96%). This essential category shows a two-way technical dependency between EV and wind power, with high penetration of both being possible.

SP oscillates between 0% and 25.00% (μ_{EV} = 13.55% and σ_{EV} = 7.17%). This is an essential category for enabling high EV and solar power penetration.

To rank the categories and estimate their relative importance and consistency over time, we defined the following two key performance indicators (KPIs).

$$KPI_{1i} = \mu_i \tag{1}$$

$$KPI_{2i} = \frac{\sigma_i}{\mu_i} \tag{2}$$

In both equations, i is the corresponding category indicated in Tables 5 and 6.

We ordered the previous categories based on these KPIs, with a higher KPI_1 value indicating greater relative presence on the part of a category and a lower the KPI_2 value indicating greater consistency and stability over time.

Table 5. KPI_1 values for each analyzed EV category.

i	GI	T	S	SP	SG	WP	E	C&S
KPI_{1i} [%]	20.42%	18.45%	17.60%	13.55%	11.58%	7.92%	5.45%	5.05%

Table 6. KPI_2 values for each analyzed EV category.

i	GI	S	T	SP	SG	WP	C&S	E
KPI_{2i}	0.26	0.37	0.38	0.53	0.71	0.75	0.99	1.00

In Tables 5 and 6, the first places (GI, T, and S) indicate the importance and temporal consistency for the subject and categories of study. Next, SP and SG have similar importance, with their order reversed by only one position based on each KPI. The next place corresponds to the WP category. Finally, the last positions are for C&S and E categories, which had the least impact on the studies.

Figure 15 presents the same type of analysis for the set of subcategories belonging to S, incorporating years and average frequency.

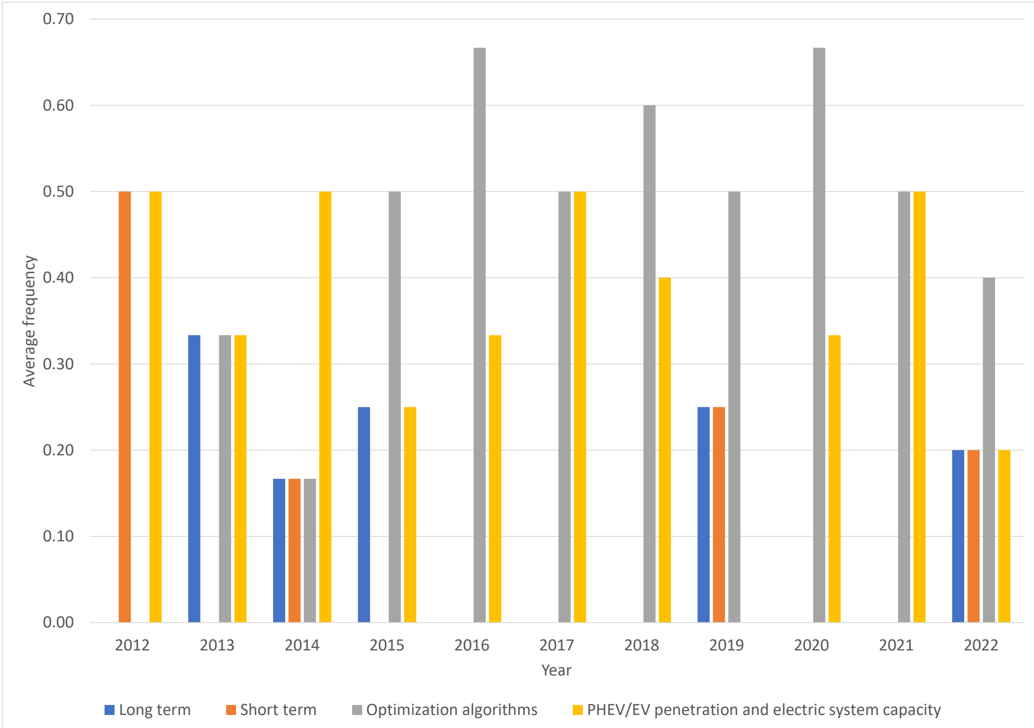

Figure 15. Temporal evolution of Simulations subcategories from 2012 to 2022.

Table 7 orders the *S* subcategories from greatest to least interest and consistency over time according to the KPIs described above. It can be concluded that the subcategory with the greatest research importance is that of optimization algorithms, which are the most interesting tool for researchers.

Table 7. *KPI* analysis of *S* subcategories.

Subcategory	KPI_{1i} [%]	KPI_{2i}
Optimization algorithms	43.94	0.47
PHEV/EV penetration and electric system capacity	35.00	0.45
Long term	10.91	1.21
Short term	10.15	1.61

Figure 16 shows a similar analysis for the T subcategories. Using the previous method, Table 8 shows the subcategories ordered from most to least important.

At a technological level, the most widely studied subcategories are ‘V2GHV or (VGI) or (G2V)’, with high research relevance. Well behind, the second subcategory of ‘Battery technology, remanufacturing, and recycling’ also accumulates a large amount of research in the study period. Solving technological problems related to both topics is essential for massive integration of EVs at the general level.

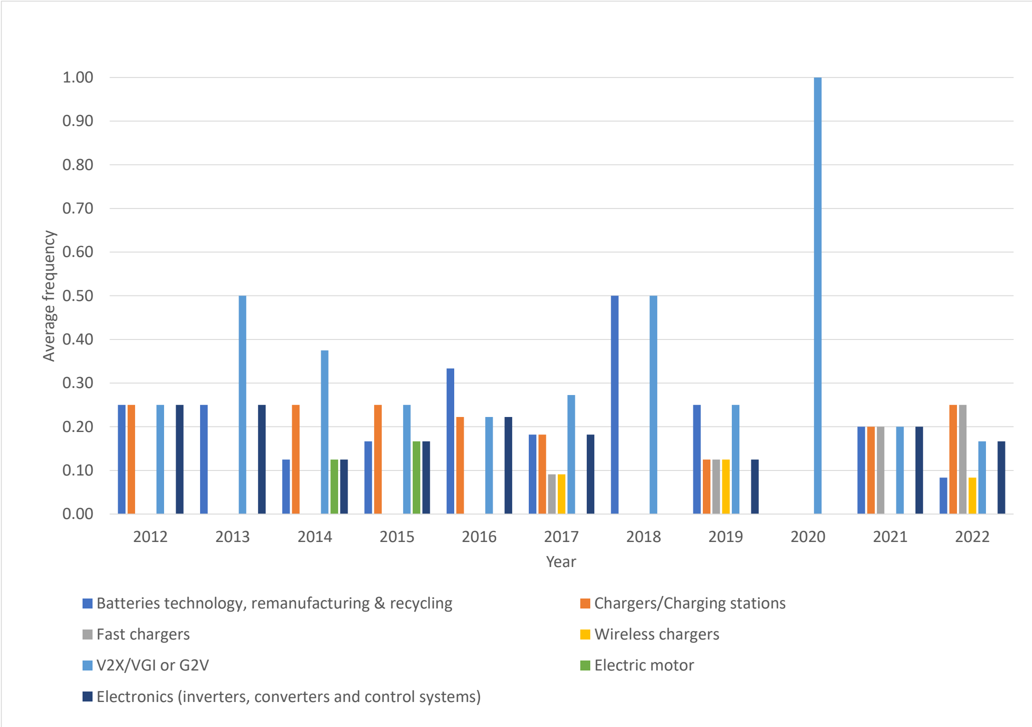

Figure 16. Temporal evolution of Technology subcategories from 2012 to 2022.

Table 8. *KPI* analysis of *T* subcategories.

Subcategory	KPI_{1i} [%]	KPI_{2i}
V2GHV or VGI or G2V	36.24	0.66
Battery technology, remanufacturing and recycling	21.27	0.62
Electronics (inverters, converters and control systems)	15.34	0.57
Chargers/Charging stations	15.72	0.69
Fast chargers	6.05	1.53
Wireless chargers	2.72	1.75
Electric motor	2.65	2.25

In the case of GI (Figure 17), using the previous method, Table 9 shows the subcategories ordered from most to least important.

Between the second and third rows of Table 9, more weight was selected for transformer congestion and line deterioration in distribution networks versus stability of power systems/grid, as the relative variation of KPI_2 (4.00%) was greater than that of KPI_1 (3.84%). Due to these small differences, both subcategories are considered equivalent in importance. The most important variable is smart charging/charge management and location. This makes perfect sense, as most articles refer to controlled and scheduled charging strategies as well as optimal location of electrical infrastructure to optimize equipment, materials, and costs. This is arguably the most promising topic of study. The following two subcategories ensure that distribution networks can support high EV penetration and that the useful life of transformers will not be limited due to overloading.

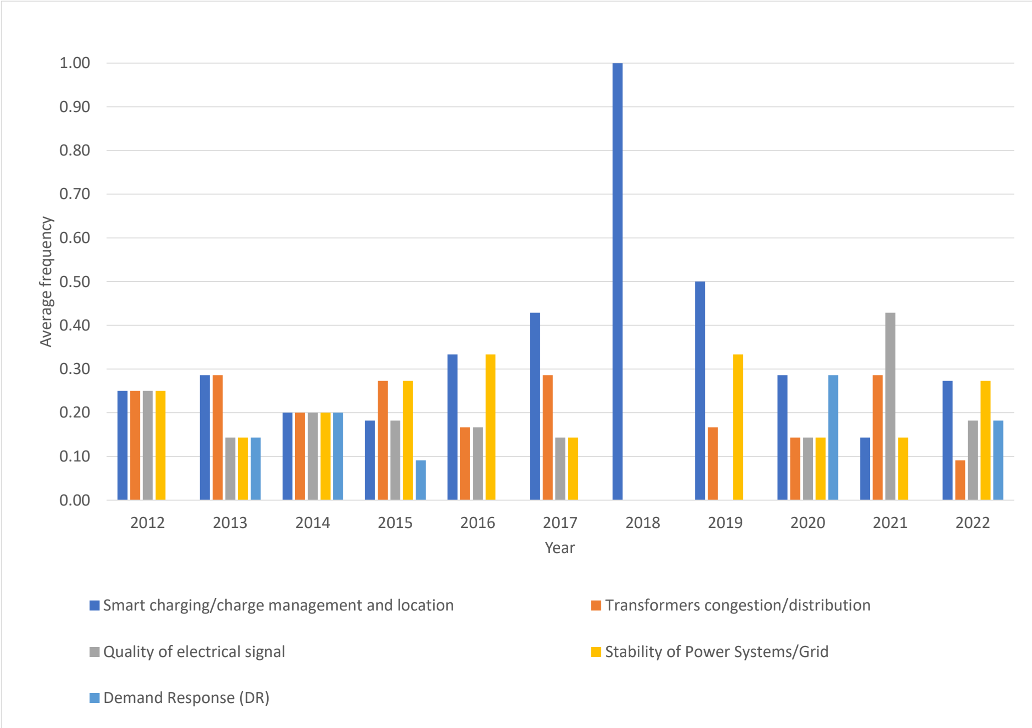

Figure 17. Temporal evolution of Grid Impact subcategories from 2012 to 2022.

Table 9. *KPI* analysis of *GI* subcategories.

Subcategory	KPI_{1i} [%]	KPI_{2i}
Smart charging/charge management and location	35.28	0.68
Transformer congestion and line deterioration in distribution networks	19.52	0.48
Stability of power systems/grid	20.30	0.50
Quality of electrical signal	16.70	0.69
Demand Response (DR)	8.19	1.28

We did not carry out this analysis on the categories that do not include any subcategories, as they were studied in the pie charts shown previously in Figure 14.

In the case of WP (Figure 18), Table 10 is obtained by applying the same analysis to the data. The first two subcategories represent two different sides of the same reality, constituting the greatest challenges for this category, namely, that high penetration of EVs and wind power is not easy if carried out separately.

Table 10. *KPI* analysis of *WP* subcategories.

Subcategory	KPI_{1i} [%]	KPI_{2i}
Shortage and quality of production (RES penetration issues)	27.58	1.40
Increments in EV and wind power facilities	16.97	1.80
Emission reduction management	16.21	1.88
Operational cost management (users and companies)	7.12	1.76
Energy efficiency vs. fossil consumption	4.84	1.72

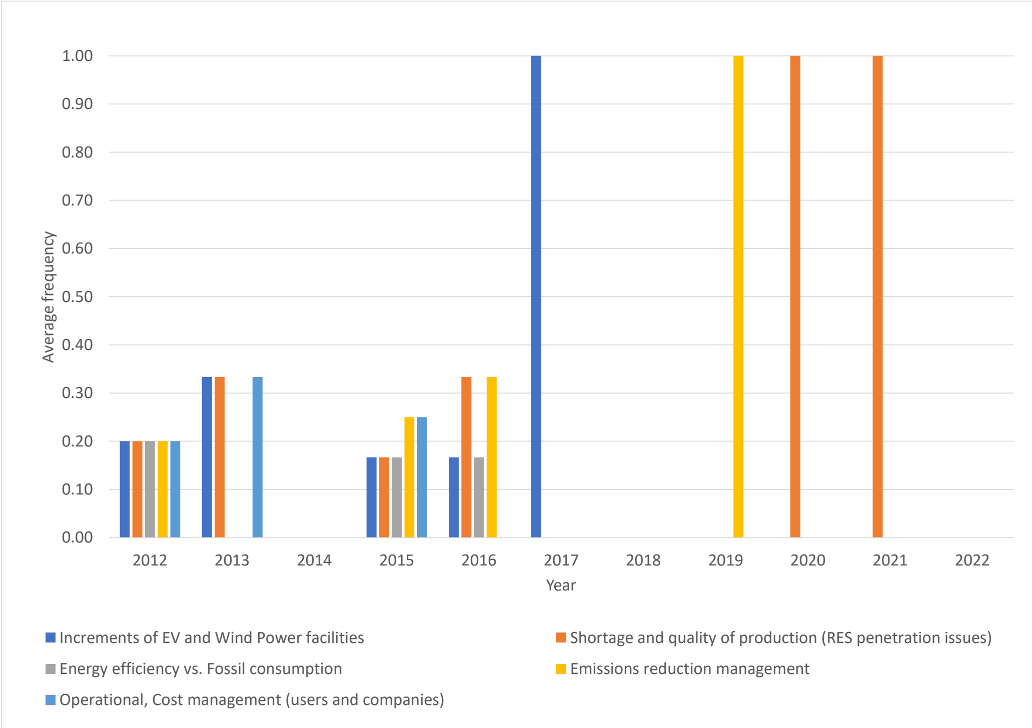

Figure 18. Temporal evolution of EV and Wind Power subcategories from 2012 to 2022.

In the case of SP (Figure 19), Table 11 was obtained by applying the same analysis to the data.

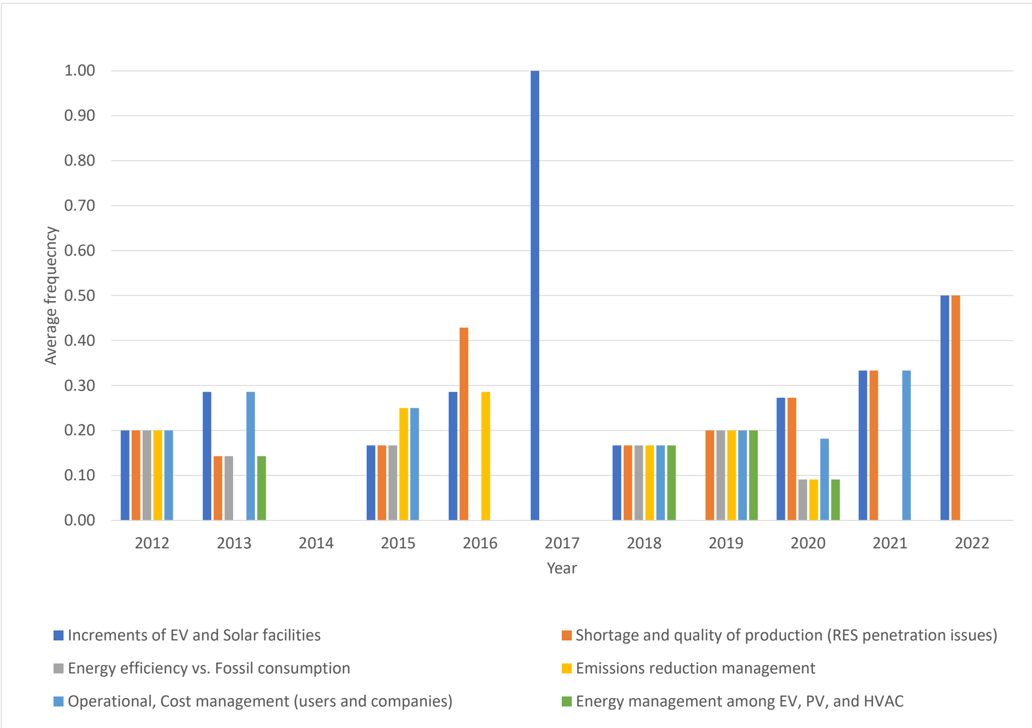

Figure 19. Temporal evolution of EV and Solar Power subcategories from 2012 to 2022.

Table 11. *KPI* analysis of *SP* subcategories.

Subcategory	KPI_{1i} [%]	KPI_{2i}
Increments in EV and solar facilities	29.19	0.94
Shortage and quality of production (RES penetration issues)	21.92	0.72
Operational cost management (users and companies)	14.7	0.86
Emission reduction management	10.85	1.05
Energy efficiency vs. fossil consumption	8.79	1.01
Energy management among EV, PV and HVAC	5.46	1.46

As in the previous case, the most important variables belong to the first two rows, with both having considerable technological interdependence. While in the previous WP category both subcategories had practically similar values, in the SP category the shortage problem is less important compared to 'Increments in EV and wind power facilities', indicating that although combination of EVs and PV is necessary for high penetration of both technologies, the integration of PV itself is less reliant on EVs for higher penetration than vice versa. This seems reasonable, as in the case of homes PV production is normally lower than the needs of the home and when PV resources are available they are normally fully consumed, making it easier to decouple PV accumulation than in the case of wind energy.

With our analysis of the selected review articles completed, a meta-analysis of the technical content of the 32 selected articles was carried out, incorporating the results of each for the selected category where appropriate. In this paper, we only perform a meta-analysis of the grid impact category, leaving the rest of the categories for a future publication.

6. Grid Impact

The main aspects that negatively impact the grid are described below. We retrieved and analyzed the results published by the scientific community in each subcategory.

6.1. Smart Charging/Charge Management and Location

The high and disruptive level of EV penetration expected over the coming years [118] will reduce fossil fuel usage while entailing high electrical demand from distribution networks which were not originally designed for this purpose, resulting in network impacts, current congestion, and voltage drops in lines and transformers [104,119]. This challenge can be addressed through the design and operation of high-quality smart grids and the use of local RES generators. These can allow surplus electricity to be stored in EVs, granting DSOs greater flexibility in managing demand peaks and valleys, active and reactive power in the network, frequency control, and spinning reserves [120].

For a better understanding of this section, Figure 20 presents a diagram showing the stakeholders and principal elements in the network.

The main network stakeholders are EVs, aggregators, and DSOs. Aggregators are an interface between EVs and DSOs that unifies a set of EVs and their individualized state variables, such as the state of charge (SoC). They are necessary for V2G strategies and are able to achieve significant loads, which can then be intelligently managed by DSOs. EV charging and discharging orders are sent to the aggregator by the DSOs based on network need. DSOs are dedicated to optimizing large electricity flows, while aggregators individualize these orders to each customer. This strategy is economically and operationally the best for all stakeholders [121].

Electricity generation, transmission, and distribution are affected differently as EV penetration increases. Generation and transmission have a wide overload safety margin by design, and as such are not greatly affected. In contrast, distribution is affected, as it has not been designed for either the level of overload that EVs can produce or for electricity generation at the distribution level. In addition, fast chargers can significantly affect distribution, a situation that could be partially alleviated if some of them were installed in the transmission part to minimize the effects. Each case should be studied separately [122].

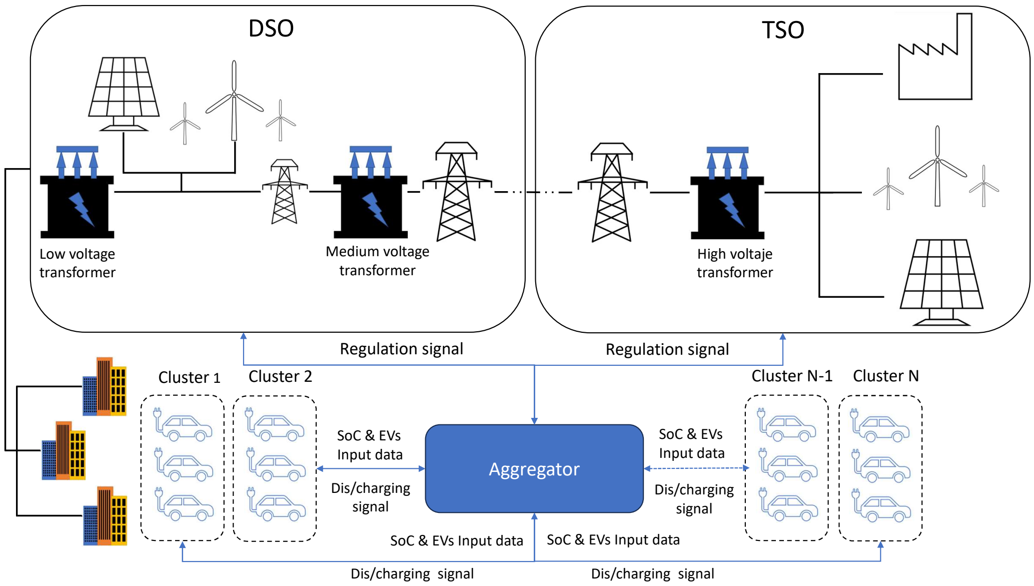

Figure 20. Main elements of an electric network in the context of EV charging.

Transmission system operators (TSOs) and DSOs are affected differently by EVs. EVs limit the variations of RES energy in transmission, absorbing energy when there is a surplus and giving it up when there is not enough renewable production. Therefore, TSOs are favored by further stabilization of the network. In the case of DSOs, high penetration of EVs produces extra loads as well as loss of quality and stability of the electrical wave, which significantly impacts the distribution network. There may sometimes be conflicts between stakeholders due to the priority of EV storage resources in terms of need. The authors of [123] proposed a list to solve these problems: (1) (TSO) emergency actions; (2) (TSO/DSO) alert actions; (3) (DSO) local voltage control; (4) (DSO) peak-shaving; (5) (TSO) voltage support; (6) (DSO) Mvarbands (7) frequency control; (8) (TSO) other ancillary services; (9) (aggregator) imbalance issues; and (10) power quality [124].

EVs connected to the grid generate different problems, such as unbalanced grid areas due to high fast-changing demands, harmonic injection, and low-power factors. Thus, it is estimated that EV penetration of 10% will increase peak demand by 17.9%, while 20% penetration will increase it to 35.8%. In the case of all impacts on a grid being controlled (power demand optimization, minimum voltage deviation, ensuring smooth load peaks, avoiding significant transformer impact, maximizing the grid load factor, maximum utilization of RES, and minimization of energy losses), one study indicates that the voltage deviation in a residential distribution network could be less than 10% for EV penetration of 30%. To reduce EV impact, smart chargers containing advanced control electronic converters must be used [125].

Uncontrolled EV charging shows investment increases in generation and transmission infrastructure as well as in operation, which can be avoided using smart charging strategies that balance the network and avoid peaks. Smart charging involves power and information transmission (SoC, voltage, current, and time to full charge). In the event that charging is unidirectional, control strategies can be used to manage the reactive power with current phase-angle control, maximizing the benefits for both aggregators and clients [126,127].

In relation to energy losses and investment costs, energy losses could increase by up to 40% in off-peak hours for a penetration up to 60% of PEVs, and up to 15% of the total actual distribution network costs would need to be invested depending on the charging strategy [125].

In an ideal model simulation, for a certain level of PEV loads, if they are fully controllable then the invoiced costs would not be increased, while even 10% non-controlled lower penetrations could increase charging costs by up to 22% [128].

Similar data obtained from other studies demonstrate the network stress produced by uncontrolled EV charging, which generates higher infrastructure costs, indicating that 60–70% of these could be eliminated if charging was carried out in a controlled way. Different authors divide the charging process into centralized and decentralized strategies. In the former, EV charging is programmed through a controller located in the charging station or in the aggregator. The variables managed are the SoC, grid situation, and electricity prices. This strategy optimizes charging for large EV penetration, a necessary requirement for the existence of aggregators. The decentralized strategy leaves the charging schedule in the hands of the owner, making it more fault-tolerant, less technically complex, and easier to scale [129].

Other more recent works explain the same concepts in greater detail, referring to them as uncoordinated or coordinated strategies. In the first case, the user decides to make a "direct" or "delayed" charge. In the "direct" case, the EV is charged when desired until it reaches a certain battery level, then is disconnected. In the "delayed" case, the EV connection is delayed to favorable periods when the network is not as saturated. Coordinated strategies use optimization, scheduling, and pricing techniques belonging to the same transformer, and can be continuous or discrete. Uncoordinated strategies refer to a charging period during which an EV is continually charged without interruption. In discrete techniques, on the other hand, the charging period is divided into a number of intervals, with the system deciding whether to charge a certain vehicle or if it is better to charge another. The advantages of these strategies increase when working with networks that allow V2GHV, although the strategies increase in complexity as well. Studies have shown that coordinated smart charging is much more efficient than uncoordinated charging [130].

In the case of bidirectional cables (V2G or V2H) [131,132] or wireless [133] charging, cost increases for the customer are involved due to degradation of the batteries, more expensive power electronics (inverters and converters), metering, and control. On the other hand, there are greater benefits for DSOs, as more stored energy is available with capacity for instant use due to using EVs as energy vectors, allowing critical aspects of the network such as active and reactive power, current harmonics, load balancing, and peak load shaving to be regulated [134,135].

Successful integration of V2G technology is related to communications systems, compatible infrastructure, and regulatory support, which differ depending on regions and market dynamics [68].

The use of a distributed charging strategy maintains user privacy and is favorable when there are low communications requirements; however, for the EV and RES high-penetration cases, it is advisable to use centralized charging, which optimizes the energy usage of the network thanks to the information provided by the communication systems. In cities and for slow or moderate charging speeds, EVs are typically parked for 22 h per day [136,137].

Regarding the location of smart chargers, while the number of EVs is undeniably increasing, wider adoption will only be possible with charging infrastructure deployment that considers the location of EV owners and their behaviors, setting two possible objectives: (1) maximization of the service provided for a given cost, or (2) minimization of the cost of charging infrastructure for a defined service level [138].

In this sense, studies have considered whether it is better to install smart chargers in a specific area or along a highway, as well as the appropriate number of chargers. Other studies have searched for the best location of these elements through optimization strategies, with other approaches calculating the spatial distribution of load demand and deducing the best locations. Study of the installation location of smart chargers allows network managers to predict the points of greatest demand within the network. Researchers have extensively studied whether current charging infrastructure is appropriate and what additions or modifications would be necessary to achieve high EV penetration [139].

In relation to EV uptake barriers, researchers have indicated that the main problems are that users are not interested in purchasing an EV when there is not enough charging infrastructure, while operators do not want to invest too much in infrastructure if there are not enough EVs. According to various authors, DSOs should invest more in charging infrastructure than in subsidizing batteries [138].

Smart charging will have an impact not only in cities, but in rural areas as well. Studies carried out to evaluate their viability by 2030 have concluded that the use of EVs in these locations is possible without building new lines or other infrastructure; however, the electric charging process must be controlled so as not to affect the electrical network [140].

Finally, new problems related to the environment, such as the dissipation of amounts of large heat and the electromagnetic compatibility of the charging stations, still need to be addressed [141].

6.2. Transformer Congestion and Line Deterioration in Distribution Networks

The transformers (medium voltage and especially low voltage) and conductors belonging to distribution networks were not designed to charge EVs. There is a significant impact on overloading of these elements when EV penetration is high. Thus, it is important for future cities and neighborhoods to consider EV charging when sizing their electrical systems [134,142].

EV geographic aggregation strategies can impact distribution networks and their elements (transformers, feeders, and branches) unless charging coordination strategies are implemented [128,132].

Other authors have concluded that electrical systems do not have the appropriate dimensions for meeting future PHEV demand. Although there are no real data yet, many simulation analyses have been performed to obtain these conclusions [121].

In Figure 20, it can be seen that there is a real risk of PEV loading in distribution networks causing deterioration of low-voltage transformers and lines [119,130]. These effects include reduced efficiency, temperature increases, and premature failure of the insulation/windings or core structure. The power electronic systems of battery chargers produce current harmonics that deteriorate transformers, impacting the efficiency and safety of smart grids. The incorporation of local RES can help to solve these problems [120].

The imbalance between phases occurring when an EV is charged in only one phase can produce overload in a line or transformer phase while the rest are unaffected, which directly impacts transformer failures [104,137].

These phenomena depend on the network zone, as overloads can be produced by a high concentration of EVs at a point while not affecting others. A detailed analysis is necessary to determine the underlying causes [131,143].

Other studies have indicated that even if EV penetration increases, with advanced smart charging strategies it would not be necessary to make new investments in generation and transmission, although it has been suggested that there would be an impact on transformers and lines during distribution [122,126,130].

Simulation studies have shown that PEV penetration levels between 17% and 31% increase transformer currents from 37% to 74% [125]. These studies have concluded that this level of penetration generates transformers losses when chargers work at level 2 or 3. For future cities or equipment replacement, it is necessary to consider that transformers and conductors must be oversized. Studies have indicated that PEV penetration of 50% could reduce transformer life by 200% to 300%. On the other hand, if loads are controlled, the lifetime can be increased by 100% to 200% compared to the previous case. Moreover, PEV penetration of 30% would increase demand by 10% in a Belgian network, exceeding the capacity of transformers and conductors. In these cases, it is proposed to deal with voltage drops by means of load-tap charging transformers or by using a capacitor bank.

The advanced use of V2G will make it possible to smooth out these effects [125], as EVs can behave as auxiliary services for network management [127].

Recent research has evaluated the impact of artificial intelligence in analyzing optimal charging and discharging scheduling in V2G systems, concluding that the operating costs of the electrical network can be significantly reduced with the use of simple algorithms [144].

6.3. Quality of Electrical Signal

High penetration of EVs and resulting incorporation of equipment with great power electronics produces current harmonics and voltage variations that deteriorate downstream equipment [125,127,131].

The effect of harmonic production, peak loading, and power quality degradation, among others, is more important when multiple EV chargers are present in the same location, that is, when installation of chargers is not planned, especially if they are fast chargers [104,137,145].

Power quality degradation can originate from voltage deviations, harmonic currents, phase imbalance, or direct current (DC) offset. In fact, one of the reasons for ending the transfer of energy between a charger and an EV is the effect of harmonics [143]. Standards such as EN 61000 and IEEE 519 establish upper limits of harmonic currents and voltages, with power factor being the quality parameter of networks without distortion; transformers and feeders typically suffer decreased value of the power factor [130,146].

It is necessary to coordinate the charging and discharging of all EVs to maintain the network quality while individualizing the monitoring of each vehicle and establishing an appropriate regulation and different charging modes that do not disturb the system [134,147].

The origin of harmonics in EV chargers is the use of converter switching, which several authors have sought to solve by incorporating specific filtering device strategies. When properly controlled, EV chargers can work as active filters and provide variable impedance for each harmonic frequency that needs to be limited [142].

Supra-harmonics are derived from fast chargers, and may have an impact on deterioration of the grid behavior. This is even more the case if the X/R ratio of distribution line is small or if there is a low short-circuit ratio and high impedance. Supra-harmonic distortion is addressed by means of an AC–DC front-end rectifier and proper input filter design. Voltage fluctuations are another type of quality problem arising as a consequence of EVs fast charging. Some authors have indicated that this problem increases if the power of the buses is increased. Similarly, voltage fluctuation is associated with installation of a fast charging station on a weak network bus [122,141].

6.4. Stability of Power Systems/Grids

Power electronics systems are increasingly present in electrical networks to regulate the greater penetration of RES, which can cause the global system to lose inertia and lead to problems with reactive power generation, frequency control, and imbalance between load and power generation [120,132,134].

Due to their power electronics, chargers can be a source of network instabilities, making it necessary to control the location of the charger, monitor the SoC of the battery, and plan EV charge/discharge strategies to avoid destabilizing the network [121,147].

The combination of charging EVs, smart grid management, and renewable production can result in configuration that, rather than destabilizing the grid, has the opposite effect. EV charging and renewable production are random and distorting grid elements in separation; however, with proper smart control and V2G use it is feasible to transport energy where it is needed, stabilize grids through ancillary services such as frequency regulation, and avoid demand peaks even when performing a fast charge [130,138].

In order for these systems to favor the stability of the network, it is necessary to accurately model the network to obtain valid results [135].

EVs can act as auxiliary services for management, network flexibility, and demand-side management [127,137].

To maintain a correct balance between demand and supply while ensuring that the electrical network works reliably, ancillary services supporting the network can be used to maintain sustainability and reliability. DSOs traditionally control local voltage and congestion prevention while TSOs control frequency (spinning and non-spinning reserve and regulation). With increased penetration of EVs and RES, DSOs will have to take on more responsibility in the spinning reserve and regulation areas [104,148].

The main ancillary service stabilizing an EV infrastructure network is the spinning reserve service (using V2G, where the energy stored in the EV is transferred to the network to collaborate or resolve situations of insufficient generation or supply failure, along with active power support/load leveling and peak load shaving), which mitigates consumption peaks or valleys at very specific times of the day caused by usage habits. In this way, "load leveling" will activate the EV charging mode, absorbing energy from the network when global electrical demand is low, while "peak load shaving" provides (injects) energy from EVs to the network when the demand is high. Reactive power support/voltage regulation/power factor correction is another service for grid reliability. It requires proper voltage and power factor regulation, which is corrected by a static reactive compensator. With the implementation of V2G, the capacitive power source can be obtained from the EV connected to the grid through its DC-link capacitor connected in a bidirectional EV charger. Thus, monitoring the EV voltage through a meter in the charger means that reactive power can be compensated for by regulating the phase angle. If grid voltage is high enough, the EV starts charging; otherwise, it stops charging [125,131,142].

Installation of EV charging stations on weak buses causes grid instability problems such as power/economic losses and voltage instability. Fast charging stations cause even more instabilities. Several simulation studies have been carried out to determine these effects, which are highly dependent on the location of the network, finding that the system takes more time to recover previous conditions. Installing RES or local storage on charging stations has been found to improve network stability [122,141,143].

6.5. Demand Response (DR)

As both the number of PEVs and their concentration in certain urban locations increase, network will be affected if appropriate strategies are not adopted. Demand responses (DR) can provide tools to deal with this issue [128,142].

DRs and demand response programs (DRP) are related to the idea that electrical systems will tend to be more efficient if fluctuations in demand are smaller. DRPs are created as incentives for customers to consume less energy at times when market prices are higher, when the electrical system is more stressed, or when it is at risk. For this reason, a large part of the success of a DRP is its predictability in terms of demand; consequently, proposals that are satisfactory to potential clients must be made in economic terms and in schedules [121,137].

Examples include Rescheduling charging power, in which a smart charger is necessary to provide variable power to a EVs within predefined limits; rescheduling the charging period, which consists of moving usual hours to other slots accepted by consumers; and power feedback or V2G, as explained above, in which DRPs are articulated by taking advantage of the large amount of stored energy for use at optimal moments in order to stabilize the network. Excellent control of these strategies could allow for high penetration of EVs with little impact on the distribution network. At the local level and focused on EV users, various groups of such vehicles which may be encompassed by buildings or other configuration of a distribution sub-grid can be managed by charging service providers (CSPs), commonly called aggregators. Through supply-and-demand strategies, the optimal objective is for all three actors to achieve financial profit. In the future, clients could access day-ahead or real-time markets without using aggregators as intermediaries [121,122,138].

In order to be successful using the aforementioned strategies, economic dispatch tools should be used to minimize operation costs under electric system safety constraints. Thus, generation should use EVs in V2G mode to stabilize production, while transmission should minimize losses by optimizing EVs location and their charging schedules. At the equipment maintenance level, optimizing the use of EV batteries should be pursued [104,123,136].

7. Conclusions

- The progressive replacement of ICEVs by solutions that do not rely on fossil fuels is ongoing around the world. One of the most promising solutions for this transition is represented by EVs. Their energy storage characteristics and support for the electric grid once the technology is consolidated can lead to notable improvements in energy resource management, mobility, and environmental impact.
- EV history provides three conclusions: first, electric transportation technology is as old or even older than that based on fossil fuels; second, between 1900 and 1930 three different propulsion technologies (electric, fossil fuel, and steam) coexisted commercially; and third, the simultaneity of previous solutions could be repeated today to address the transition in vehicle propulsion systems, with consumers potentially being able to opt for EVs, hydrogen vehicles (fuel cell or combustion), or vehicles powered by new synthetic fuels. Another possibility is that a balance between these three variants could be reached, potentially coexisting indefinitely.
- From 1970 onwards, the EU has championed the global decarbonization initiative, increasingly limiting CO_2 emissions and different pollutants. Euro 7 will be the latest regulation leading the continent towards emissions neutrality from vehicles.
- The rate of EV incorporation in society up to 2035 will result in overload in electrical networks, as they were not initially designed for EVs. It is foreseeable that there may be local effects based on the size of a city's distribution network. It is possible that the maximum design power per home may be exceeded when connecting level 2 EVs if all users do so at the same time. This can directly impact the main elements of the distribution network, with power lines subjected to overheating and transformers to constant overloads, resulting in consequent loss of useful life. Different strategies can allow the use of existing infrastructure to be safely maximized through detailed study of each use case and the active management of user demand.
- According to our meta-analysis, the increase in EVs will allow RES penetration to be higher, as EVs can act as storage when there is an overproduction of electricity and release stored energy when the network has insufficient production. Thus, EVs act as a stabilizing element of the network when working together with RES. Therefore, greater penetration of EVs allows more surplus renewable production to be absorbed and makes more storage available when necessary. Furthermore, the objective of greater renewable penetration requires having storage and action mechanisms in case of faults.

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Abbreviations

The following abbreviations are used in this manuscript:

AC	Alternating Current
BEV	Battery-Electric Vehicles
C&S	Cost, energy, and pollution savings using EV instead ICEV
CO	Carbon monoxide

CO_2	Carbon dioxide
CSP	Charging Service Providers
DC	Direct Current
DER	Distributed Energy Resources
DR	Demand Response
DRP	Demand Response Programs
DSO	Distributed Systems Operators
DSR	Demand-Side Response
E	Emissions reduction management in relation to ICEV without RES
EC	European Commission
EU	European Union
EV	Electric Vehicle
G2V	Grid To Vehicle
GHG	Greenhouse Gas
GI	Grid Impact
HC	Hydrocarbons
HEV	Hybrid Electric Vehicles
HVAC	Heat, Ventilation, and Air Conditioning
ICEV	Internal Combustion Engine Vehicle
IEA	International Energy Agency
IoT	Internet of Things
KPI	Key Performance Indicator
Ni-MH	Nickel–Metal Hydride
NOx	Nitrogen oxides
PEV	Plug-in Electric Vehicles
PHEV	Plug-in Hybrid Electric Vehicles
PV	Photovoltaic energy
R	Electrical Resistance
RES	Renewable Energy Sources
S	Simulations
SG	Smart Grid technologies
SoC	State of Charge
SP	EV and Solar Power
T	Technology
TSO	Transmission System Operators
UNFCCC	United Nations Framework Convention on Climate Change
US	United States
V2G	Vehicle-to-Grid
V2GHV	Vehicle-to-Grid/Home/Vehicle
V2H	Vehicle-to-Home
VGI	Vehicle Grid Integration
WHO	World Health Organization
WP	Wind power
X	Electrical Reactance

Appendix A. Information on Selected Review Studies

The following tables list the review studies selected for this paper. They include the study identifier (S1 to S32), year of publication, main author, and bibliographic reference.

Table A1. Selected review articles (S1–S6) per year and main author.

Study	S1	S2	S3	S4	S5	S6
Year	2012	2013	2013	2014	2014	2014
Main author	Murat Yilmaz [125]	David B. Richardson [126]	Wei Gu [121]	Ahmed M.A. Haidar [147]	Pranav Maheshwari [127]	Xianjun Zhang [128]

Table A2. Selected review articles (S7–S12) per year and main author.

Study	S7	S8	S9	S10	S11	S12
Year	2015	2015	2015	2016	2016	2016
Main author	Liansheng Liu [120]	Salman Habib [134]	Jia Ying Yong [142]	Junjie Hu [148]	Abdul Rauf Bhatti [124]	Kang Miao Tan [131]

Table A3. Selected review articles (S13–S18) per year and main author.

Study	S13	S14	S15	S16	S17	S18
Year	2017	2017	2017	2018	2018	2018
Main author	Ashique, R. H [143]	Ahmad, A. [133]	Sovacool, B. K. [119]	Thompson, A. W [149]	Shepero, M. [129]	Hoarau, Q. [118]

Table A4. Selected review articles (S19–S24) per year and main author.

Study	S19	S20	S21	S22	S23	S24
Year	2019	2019	2019	2019	2020	2020
Main author	Collin, R. [132]	Pagany, R. [139]	Li, Z. [150]	Barone, G. [135]	Mohammad, A. [137]	Arias-Londoño, A. [104]

Table A5. Selected review articles (S25–S30) per year and main author.

Study	S25	S26	S27	S28	S29	S30
Year	2020	2020	2021	2021	2021	2022
Main author	Fachrizal, R. [136]	Ding, Z. [123]	Aretxabaleta, I. [146]	El-Bayeh, C. Z. [130]	Eltoumi, F. M. [145]	Rahman, S. [122]

Table A6. Selected review articles (S31–S32) per year and main author.

Study	S31	S32
Year	2022	2022
Main author	Metais, M. O. [138]	Safayatullah, M. [141]

References

1. Emadi, A.; Rajashekara, K.; Williamson, S.S.; Lukic, S.M. Topological overview of hybrid electric and fuel cell vehicular power system architectures and configurations. *IEEE Trans. Veh. Technol.* **2005**, *54*, 763–770. [CrossRef]
2. Larminie, J.; Lowry, J. *Electric Vehicle Technology Explained*; John Willey and Sons: Hoboken, NJ, USA , 2003.
3. Wirasingha, S.G.; Emadi, A. Pihef: Plug-in hybrid electric factor. In Proceedings of the 2009 IEEE Vehicle Power and Propulsion Conference, Dearborn, Michigan, 7–11 September 2009; IEEE: Piscataway, NJ, USA, 2009; pp. 661–668.

4. Earth Science Communications Team at NASA's Jet Propulsion Laboratory—California Institute of Technology. Ice Sheets. Available online: https://climate.nasa.gov/vital-signs/ice-sheets/ (accessed on 12 July 2023).
5. Cook, J.; Nuccitelli, D.; Green, S.A.; Richardson, M.; Winkler, B.; Painting, R.; Skuce, A. Quantifying the consensus on anthropogenic global warming in the scientific literature. *Environ. Res. Lett.* **2013**, *8*, 024024. [CrossRef]
6. International Energy Agency. Energy Technology Perspectives. 2012. Available online: https://www.iea.org/reports/energy-technology-perspectives-2012 (accessed on 12 July 2023).
7. Darabi, Z.; Ferdowsi, M. Impact of plug-in hybrid electric vehicles on electricity demand profile. *Smart Power Grids* **2012**, *2011*, 319–349.
8. European Environment Agency. *Greenhouse Gas Emissions from Transport in Europe*; Technical Reports; EEA: Copenhagen, Denmark, 2019.
9. Hawkins, T.R.; Singh, B.; Majeau-Bettez, G.; Strømman, A.H. Comparative environmental life cycle assessment of conventional and electric vehicles. *J. Ind. Ecol.* **2013**, *17*, 53–64. [CrossRef]
10. MacInnis, B.; Krosnick, J.A. Climate Insights 2020: Surveying American Public Opinion on Climate Change and the Environment. 2020. Available online: https://media.rff.org/documents/Climate_Insights_2020_Electric_Vehicles.pdf (accessed on 13 July 2023).
11. Center for Climate and Energy Solutions. US Emissions. Available online: https://www.c2es.org/content/u-s-emissions/ (accessed on 12 July 2023).
12. United States Environmetal Protection Agency. Sources of Greenhouse Gas Emissions. Available online: https://www.epa.gov/ghgemissions/sources-greenhouse-gas-emissions (accessed on 14 July 2023).
13. International Energy Agency. Oil Market Report. June 2022. Available online: https://www.iea.org/reports/oil-market-report-june-2022 (accessed on 14 July 2023).
14. International Energy Agency. World Energy Investment 2023. May 2023. Available online: https://iea.blob.core.windows.net/assets/8834d3af-af60-4df0-9643-72e2684f7221/WorldEnergyInvestment2023.pdf (accessed on 22 July 2023).
15. Chan, C.K.; Yao, X. Air pollution in mega cities in China. *Atmos. Environ.* **2008**, *42*, 1–42. [CrossRef]
16. Liang, L.; Gong, P. Urban and air pollution: A multi-city study of long-term effects of urban landscape patterns on air quality trends. *Sci. Rep.* **2020**, *10*, 18618. [CrossRef]
17. Zhang, X.; Karady, G.G.; Piratla, K.R.; Ariaratnam, S.T. Network capacity assessment of combined heat and power-based distributed generation in urban energy infrastructures. *IEEE Trans. Smart Grid* **2013**, *4*, 2131–2138. [CrossRef]
18. Paliwal, P. Comprehensive analysis of distributed energy resource penetration and placement using probabilistic framework. *IET Renew. Power Gener.* **2021**, *15*, 794–808. [CrossRef]
19. United States Environmetal Protection Agency. Summary of the Energy Independence and Security Act. Available online: https://www.epa.gov/laws-regulations/summary-energy-independence-and-security-act (accessed on 23 July 2023).
20. European Commission. REPowerEU. Available online: https://commission.europa.eu/strategy-and-policy/priorities-2019-2024/european-green-deal/repowereu-affordable-secure-and-sustainable-energy-europe (accessed on 22 July 2023).
21. Xu, C.; Behrens, P.; Gasper, P.; Smith, K.; Hu, M.; Tukker, A.; Steubing, B. Electric vehicle batteries alone could satisfy short-term grid storage demand by as early as 2030. *Nat. Commun.* **2023**, *14*, 119. [CrossRef]
22. European Commission. 2030 Climate Energy Framework. Available online: https://climate.ec.europa.eu/eu-action/climate-strategies-targets/2030-climate-energy-framework (accessed on 24 July 2023).
23. Eurostat. Battery-Only Electric Passenger Cars: +76% in 2021. Available online: https://ec.europa.eu/eurostat/en/web/products-eurostat-news/w/ddn-20230131-2 (accessed on 25 July 2023).
24. Ravi, S.S.; Aziz, M. Utilization of electric vehicles for vehicle-to-grid services: Progress and perspectives. *Energies* **2022**, *15*, 589. [CrossRef]
25. de Lima, S.C.; Rodrigues, A.S.; Magalhães, V.A.N.; Lopes, I.Â.P. Challenges of the Deployment of Electric Cars in Brazil. *J. Eng. Res.* **2022**, *2*, 1317–2764.
26. Morimoto, M. Which is the first electric vehicle? *Electr. Eng. Jpn.* **2015**, *192*, 31–38. [CrossRef]
27. Vepachedu, S.; Institutes, N.; View, E.; View, G.; Vepachedu, S. The history of the electric car. *Andhra J. Ind. News* **2017**, *8*, 14–27.
28. Guarnieri, M. Looking back to electric cars. In Proceedings of the 2012 Third IEEE HISTory of ELectro-Technology CONference (HISTELCON), Pavia, Italy, 5–7 September 2012; IEEE: Piscataway, NJ, USA, 2012; pp. 1–6.
29. Henderson, M. Developments in lead-acid batteries. *Electron. Power* **1977**, *23*, 491–493. [CrossRef]
30. Ren, G.; Wang, J.; Chen, C.; Wang, H. A variable-voltage ultra-capacitor/battery hybrid power source for extended range electric vehicle. *Energy* **2021**, *231*, 120837. [CrossRef]
31. Kiyakli, A.O.; Solmaz, H. Modeling of an electric vehicle with MATLAB/Simulink. *Int. J. Automot. Sci. Technol.* **2018**, *2*, 9–15. [CrossRef]
32. Hiziroglu, A.B. The Car: A Brief History. In *Autonomous Vehicles and the Law: How Each Field Is Shaping the Other*; Springer International Publishing: Cham, The Netherlands, 2020; pp. 1–10.
33. Faraz, A.; Ambikapathy, A.; Thangavel, S.; Logavani, K.; Arun Prasad, G. Battery electric vehicles (BEVs). In *Electric Vehicles: Modern Technologies and Trends*; Springer: Singapore, 2021; pp. 137–160.
34. Upadhyay, A.; Dalal, M.; Sanghvi, N.; Singh, V.; Nair, S.; Scurtu, I.C.; Dragan, C. Electric Vehicles over Contemporary Combustion Engines. In *IOP Conference Series: Earth and Environmental Science*; IOP Publishing: Bristol, UK, 2021; Volume 635, p. 012004.
35. Anderson, C.D.; Anderson, J. *Electric and Hybrid Cars: A History*; McFarland: Jefferson, NC, USA, 2010.

36. Joseph, P.K.; Devaraj, E.; Gopal, A. Overview of wireless charging and vehicle-to-grid integration of electric vehicles using renewable energy for sustainable transportation. *IET Power Electron.* **2019**, *12*, 627–638. [CrossRef]
37. Burkert, A. Electric Motor in Pole Position. *MTZ Worldw.* **2019**, *80*, 6–7. [CrossRef]
38. Paine, C.; Deeter, J.; Devlin, D.; Titus, T.M.; Titus, R.D.; Gibney, A.; Brook, M. Who Killed the Electric Car? 2006. Available online: https://cir.nii.ac.jp/crid/1130000796359381120 (accessed on 27 July 2023).
39. Iulia, V.; Loránd, S. A Brief History of Electric Vehicles. *J. Comput. Sci. Control. Syst.* **2022**, *15*, 19–26.
40. Skrabec, Q.R., Jr. *The Green Vision of Henry Ford and George Washington Carver: Two Collaborators in the Cause of Clean Industry*; McFarland: Jefferson, NC, USA, 2013.
41. Boyd, T.A. The self-starter. *Technol. Cult.* **1968**, *9*, 585–591. [CrossRef]
42. Chau, K.T.; Wong, Y.S. Overview of power management in hybrid electric vehicles. *Energy Convers. Manag.* **2002**, *43*, 1953–1968. [CrossRef]
43. Wakefield, E.H. *History of the Electric Automobile: Hybrid Electric Vehicles*; SAE International: Warrendale, PA, USA, 1998; Volume 187.
44. Díaz-Comas, A.A.; Tapia, H.J.C.L.; Serrano, R.V.C. Multi-Port Novel Topology of a DC-DC Converter for Electric Vehicle Application. Available online: https://www.researchgate.net/profile/Alfredo-Alvarez-7/publication/333207614_Multi-Port_Novel_Topology_of_a_DC-DC_Converter_for_Electric_Vehicle_Application/links/5dc43ffda6fdcc2d2ffb5a8c/Multi-Port-Novel-Topology-of-a-DC-DC-Converter-for-Electric-Vehicle-Application.pdf (accessed on 27 July 2023).
45. Rajashekara, K. History of electric vehicles in General Motors. *IEEE Trans. Ind. Appl.* **1994**, *30*, 897–904. [CrossRef]
46. Taylor, J. *Electric Cars*; Bloomsbury Publishing: London, UK, 2022; Volume 890.
47. Kurtz, D.W.; Price, T.W.; Bryant, J.A. Performance Testing and System Evaluation of the DOE ETV-1 Electric Vehicle. *SAE Trans.* **1981**, *90*, 1581–1594.
48. Chan, C.C.; Chau, K.T. *Modern Electric Vehicle Technology*; Oxford University Press: Oxford, UK, 2001; Volume 47.
49. Faiz, A.; Weaver, C.S.; Walsh, M.P. *Air Pollution from Motor Vehicles: Standards and Technologies for Controlling Emissions*; World Bank Publications: Chicago, IL, USA, 1996.
50. Banerjee, P.; Franco, A., Jr.; Xiao, R.Z.; Naidu, K.C.B.; Rao, R.M.; Pothu, R.; Boddula, R. Advancement in electrolytes for rechargeable batteries. In *Rechargeable Batteries: History, Progress, and Applications*; Wiley Online Library; 2020; Chapter 5 ; pp. 87–98. Available online: https://onlinelibrary.wiley.com/doi/abs/10.1002/9781119714774.ch5 (accessed on 28 July 2023)
51. Dulcich, F.; Porta, F.; Ubogui, M.; Baruj, G. The transition to electric mobility: Opportunities for the automotive value chain in Argentina. *Int. J. Automot. Technol. Manag.* **2022**, *22*, 374–400. [CrossRef]
52. Nonaka, I.; Peltokorpi, V. Knowledge-based view of radical innovation: Toyota Prius case. In *Innovation, Science, and Institutional Change: A Research Handbook*; Oxford University Press: Oxford, UK, 2006; pp. 88–104.
53. Eberhard, M.; Tarpenning, M. The 21 st century electric car tesla motors. *Tesla Mot.* **2006**, *17*. Available online: https://idc-online.com/technical_references/pdfs/electrical_engineering/Tesla_Motors.pdf (accessed on 27 July 2023).
54. Millet Biosca, L. Development of an Empirically-Based Numerical Model for the BTMS Design of an EV's Lithiumion Battery Pack. Master's Thesis, Universitat Politècnica de Catalunya, Barcelona, Spain, 2016
55. Rizzoni, G.; Cooke, D.; Pastor, G. The fastest electric vehicles on earth: A history of electric land speed racing and of the Venturi Buckeye Bullet program. In *15. Internationales Stuttgarter Symposium: Automobilund Motorentechnik*; Springer Fachmedien: Wiesbaden, Germany, 2015; pp. 1129–1130.
56. Frolov, A. Charging Technologies and Its Future Development of Electric Vehicles. 2017. Available online: https://www.theseus.fi/bitstream/handle/10024/128355/final_really_final_thesis_Frolov.pdf?sequence=1 (accessed on 28 July 2023).
57. Duhon, A.N.; Sevel, K.S.; Tarnowsky, S.A.; Savagian, P.J. Chevrolet volt electric utilization. *SAE Int. J. Altern. Powertrain* **2015**, *4*, 269–276. [CrossRef]
58. Kyznetsov, D.A. Ecological Electric Vihicles. In *Recent Achievements and Prospects of Innovations and Technologies*; Federal State Educational Institution of Higher Education Sevastopol State University. 2017; pp. 45–48. Available online: https://elibrary.ru/item.asp?id=29268833 (accessed on 28 July 2023).
59. Eberle, U.; Von Helmolt, R. Sustainable transportation based on electric vehicle concepts: A brief overview. *Energy Environ. Sci.* **2010**, *3*, 689–699. [CrossRef]
60. Car of the Year. News. Ampera/Volt Sweeps on Car of the Year 2012. 3 May 2012. Available online: https://www.caroftheyear.org/winners/2012/index.php (accessed on 16 July 2024).
61. Kremer, M. Electromagnetic Design of a Disc Rotor Electric Machine as Integrated Motor-Generator for Hybrid Vehicles. Ph.D. Thesis, Université de Haute Alsace-Mulhouse, Mulhouse, France, 2016.
62. Toensmeier, P. Mass Appeal: High-performance thermoplastics spark automakers' relentless drive to reduce weight and increase fuel economy. *Plast. Eng.* **2013**, *69*, 6–14. [CrossRef]
63. Schneider, T. Rightsizing. *MTZ Worldw.* **2024**, *85*, 14–15. [CrossRef]
64. Evans, R. *Opportunity Knocks*; Electric and Hybrid Vehicle Technology International; 2019; Volume 2018, No. 2. Available online: https://www.magonlinelibrary.com/doi/abs/10.12968/S1467-5560%2822%2960420-2 (accessed on 28 July 2023).
65. Auto Bild. The e-Miles: Así es el Coche eléCtrico Impreso en 3D. Available online: https://www.autobild.es/noticias/miles-coche-electrico-impreso-3d-940361 (accessed on 28 July 2023).

66. Spiteri, G. The Future of Truck Driving in America. Available online: https://aegai.nd.edu/assets/499324/spiterigareth_case_study_trucks.pdf (accessed on 28 July 2023).
67. Li, D.C.; Felix, J.R.; Chin, Y.L.; Jusuf, L.V.; Susanto, L.J. Integrated Extended Kalman Filter and Deep Learning Platform for Electric Vehicle Battery Health Prediction. *Appl. Sci.* **2024**, *14*, 4354. [CrossRef]
68. Zentani, A.; Almaktoof, A.; Kahn, M.T. A Comprehensive Review of Developments in Electric Vehicles Fast Charging Technology. *Appl. Sci.* **2024**, *14*, 4728. [CrossRef]
69. Lewicki, W.; Niekurzak, M.; Sendek-Matysiak, E. Electromobility Stage in the Energy Transition Policy—Economic Dimension Analysis of Charging Costs of Electric Vehicles. *Energies* **2024**, *17*, 1934. [CrossRef]
70. Climate Watch. 2024. Washington, DC: World Resources Institute. Available online: https://www.climatewatchdata.org (accessed on 22 July 2024).
71. Jia, L.; Ma, J.; Cheng, P.; Liu, Y. A perspective on solar energy-powered road and rail transportation in China. *CSEE J. Power Energy Syst.* **2020**, *6*, 760–771.
72. Desantes, J.M.; Molina, S.; Novella, R.; López-Juárez, M. Comparative global warming impact and NOX emissions of conventional and hydrogen automotive propulsion systems. *Energy Convers. Manag.* **2020**, *221*, 113137. [CrossRef]
73. Council of the European Communities. Council Directive 70/220/EEC of 20 March 1970 on the approximation of the laws of the Member States relating to measures to be taken against air pollution by gases from positive-ignition engines of motor vehicles. *Off. J. Eur. Comm.* **1970**, *76*, 1–22.
74. European Commission. Council Directive 91/441/EEC of 26 June 1991 Amending Directive 70/220/EEC on the Approximation of the Laws of the Member States Relating to Measures to Be Taken against Air Pollution by Emissions from Motor Vehicles. *Off. J. Eur. Union.* **1991**. Available online: https://eur-lex.europa.eu/legal-content/en/ALL/?uri=CELEX%ANTONIO:IincludetheURL:%
75. EUR-Lex. Directive 94/12/EC of the European Parliament and the Council of 23 March 1994 relating to measures to be taken against air pollution by emissions from motor vehicles and amending Directive 70/220/EEC. Available online: https://eur-lex.europa.eu/legal-content/en/ALL/?uri=CELEX%3A31994L0012 (accessed on 12 July 2023).
76. EUR-Lex. Directive 98/69/EC of the European Parliament and of the Council of 13 October 1998 Relating to Measures to Be Taken against Air Pollution by Emissions from Motor Vehicles and Amending Council Directive 70/220/EEC. Available online: https://eur-lex.europa.eu/legal-content/EN/ALL/?uri=CELEX%3A31998L0069 (accessed on 1 August 2023).
77. EUR-Lex. Commission Directive 2002/80/EC of 3 October 2002 Adapting to Technical Progress Council Directive 70/220/EEC Relating to Measures to Be Taken against Air Pollution by Emissions from Motor Vehicles (Text with EEA relevance). Available online: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A32002L0080 (accessed on 1 August 2023).
78. EUR-Lex. Regulation (EC) No 715/2007 of the European Parliament and of the Council of 20 June 2007 on Type Approval of Motor Vehicles with Respect to Emissions from Light Passenger and Commercial Vehicles (Euro 5 and Euro 6) and on Access to Vehicle Repair and Maintenance Information (Text with EEA Relevance). Available online: https://eur-lex.europa.eu/legal-content/EN/ALL/?uri=CELEX%3A32007R0715 (accessed on 1 August 2023).
79. EUR-Lex. Commission Regulation (EU) No 459/2012 of 29 May 2012 Amending Regulation (EC) No 715/2007 of the European Parliament and of the Council and Commission Regulation (EC) No 692/2008 as Regards Emissions from Light Passenger and Commercial Vehicles (Euro 6) Text with EEA Relevance. Available online: https://eur-lex.europa.eu/eli/reg/2012/459/oj (accessed on 1 August 2023).
80. EUR-Lex. Commission Regulation (EU) 2016/646 of 20 April 2016 Amending Regulation (EC) No 692/2008 as Regards Emissions from Light Passenger and Commercial Vehicles (Euro 6) (Text with EEA Relevance). Available online: https://eur-lex.europa.eu/eli/reg/2016/646/oj (accessed on 1 August 2023).
81. Zhang, N.; Huang, Z.; Wang, X.; Zheng, B. Combustion and emission characteristics of a turbo-charged common rail diesel engine fuelled with diesel-biodiesel-DEE blends. *Front. Energy* **2011**, *5*, 104–114. [CrossRef]
82. EUR-Lex. Directive 2003/30/EC of the European Parliament and of the Council of 8 May 2003 on the Promotion of the Use of Biofuels or Other Renewable Fuels for Transport. Available online: https://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=CELEX:32003L0030:EN:HTML (accessed on 1 August 2023).
83. Quadrelli, R.; Peterson, S. The energy-climate challenge: Recent trends in CO_2 emissions from fuel combustion. *Energy Policy* **2007**, *35*, 5938–5952. [CrossRef]
84. EUR-Lex. COM(2007) 19 Final-Communication from the Commission to the Council and the European Parliament. Results of the Review of the Community Strategy to Reduce CO_2 Emissions from Passenger Cars and Light-Commercial Vehicles. Available online: https://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=COM:2007:0019:FIN:en:PDF (accessed on 2 August 2023).
85. EUR-Lex. Regulation (EC) No 443/2009 of the European Parliament and of the Council of 23 April 2009 Setting Emission Performance Standards for New Passenger Cars as Part of the Community's Integrated Approach to Reduce CO_2 Emissions from Light-Duty Vehicles (Text with EEA Relevance). Available online: https://eur-lex.europa.eu/legal-content/EN/ALL/?uri=CELEX%3A32009R0443 (accessed on 2 August 2023).
86. EUR-Lex. Regulation (EU) 2019/631 of the European Parliament and of the Council of 17 April 2019 Setting CO_2 Emission Performance Standards for New Passenger Cars and for New Light Commercial Vehicles, and Repealing Regulations (EC) No 443/2009 and (EU) No 510/2011 (Recast) (Text with EEA Relevance). Available online: https://eur-lex.europa.eu/legal-content/en/TXT/?uri=CELEX%3A32019R0631 (accessed on 3 August 2023).

87. European Commission. SWD(2018) 461 Final. Commission Staff Working Document Evaluation of the EU Strategy on Adaptation to Climate Change Accompanying the Document Report from the Commission to the European Parliament and the Council on the Implementation of the EU Strategy on Adaptation to Climate Change. Available online: https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:52018SC0461&rid=1 (accessed on 3 August 2023).
88. European Commission. Climate Action. 2050 long-Term Strategy. Available online: https://climate.ec.europa.eu/eu-action/climate-strategies-targets/2050-long-term-strategy (accessed on 3 August 2023).
89. Council of the European Union. European Council Conclusions, 12 December 2019. Available online: https://www.consilium.europa.eu/en/press/press-releases/2019/12/12/european-council-conclusions-12-december-2019 (accessed on 4 August 2023).
90. United Nations. Climate Change. Long-Term Low Greenhouse Gas Emission Development Strategy of the European Union and Its Member States. Available online: https://unfccc.int/documents/210328 (accessed on 4 August 2023).
91. European Commission. A European Green Deal. Striving to Be the First Climate-Neutral Continent. Available online: https://commission.europa.eu/strategy-and-policy/priorities-2019-2024/european-green-deal (accessed on 5 August 2023).
92. European Commission. Climate Action. European Climate Law. Available online: https://climate.ec.europa.eu/eu-action/european-green-deal/european-climate-law (accessed on 6 August 2023).
93. Council of the European Union. Fit for 55. Available online: https://www.consilium.europa.eu/en/policies/green-deal/fit-for-55-the-eu-plan-for-a-green-transition/ (accessed on 6 August 2023).
94. European Commission. Zero Emission Vehicles: First 'Fit for 55' Deal Will End the Sale of New CO_2 Emitting Cars in Europe by 2035. Available online: https://ec.europa.eu/commission/presscorner/detail/en/ip_22_6462 (accessed on 7 August 2023).
95. Anika, O.C.; Nnabuife, S.G.; Bello, A.; Okoroafor, E.R.; Kuang, B.; Villa, R. Prospects of low and zero-carbon renewable fuels in 1.5-degree net zero emission actualisation by 2050: A critical review. *Carbon Capture Sci. Technol.* **2022**, *5*, 100072. [CrossRef]
96. International Energy Agency. Trends in Electric Light-Duty Vehicles. Available online: https://www.iea.org/reports/global-ev-outlook-2023/trends-in-electric-light-duty-vehicles (accessed on 8 August 2023).
97. International Energy Agency. Global EV Data Explorer. Available online: https://www.iea.org/data-and-statistics/data-tools/global-ev-data-explorer?gclid=EAIaIQobChMImYyrs9HK_wIVB_N3Ch1QXQVfEAMYAiAAEgKjMvD_BwE (accessed on 8 August 2023).
98. Boletín Oficial del Estado. Real Decreto-ley 29/2021, de 21 de Diciembre, por el que se Adoptan Medidas Urgentes en el ámbito energéTico Para el Fomento de la Movilidad eléCtrica, el Autoconsumo y el Despliegue de Energías Renovables. Available online: https://www.boe.es/eli/es/rdl/2021/12/21/29/con (accessed on 9 January 2024).
99. European Commission. Commission Proposes New Euro 7 Standards to Reduce Pollutant Emissions from Vehicles and Improve air Quality. Available online: https://ec.europa.eu/commission/presscorner/detail/en/ip_22_6495 (accessed on 8 August 2023).
100. Thingvad, A.; Andersen, P.B.; Unterluggauer, T.; Træholt, C.; Marinelli, M. Electrification of personal vehicle travels in cities-Quantifying the public charging demand. *ETransportation* **2021**, *9*, 100125. [CrossRef]
101. Soares, L.; Wang, H. Economic feasibility analysis of charging infrastructure for electric ground fleet in airports. *Transp. Res. Rec.* **2021**, *2675*, 1–12. [CrossRef]
102. Ardeshiri, A.; Rashidi, T.H. Willingness to pay for fast charging station for electric vehicles with limited market penetration making. *Energy Policy* **2020**, *147*, 111822. [CrossRef]
103. IEA. Global EV Outlook 2024, IEA, Paris 2024. Licence: CC BY 4.0. Available online: https://www.iea.org/reports/global-ev-outlook-2024 (accessed on 4 July 2024).
104. Arias-Londoño, A.; Montoya, O.D.; Grisales-Noreña, L.F. A chronological literature review of electric vehicle interactions with power distribution systems. *Energies* **2020**, *13*, 3016. [CrossRef]
105. Orr, J.A.; Emanuel, A.E.; Pileggi, D.J. Current harmonics, voltage distortion, and powers associated with electric vehicle battery chargers distributed on the residential power system. *IEEE Trans. Ind. Appl.* **1984**, *4*, 727–734. [CrossRef]
106. Rahman, S.; Shrestha, G.B. An investigation into the impact of electric vehicle load on the electric utility distribution system. *IEEE Trans. Power Deliv.* **1993**, *8*, 591–597. [CrossRef]
107. Staats, P.T.; Grady, W.M.; Arapostathis, A.; Thallam, R.S. A statistical analysis of the effect of electric vehicle battery charging on distribution system harmonic voltages. *IEEE Trans. Power Deliv.* **1998**, *13*, 640–646. [CrossRef]
108. Koyanagi, F.; Inuzuka, T.; Uriu, Y.; Yokoyama, R. Monte Carlo simulation on the demand impact by quick chargers for electric vehicles. In Proceedings of the 1999 IEEE Power Engineering Society Summer Meeting, Conference Proceedings (Cat. No. 99CH36364), Edmonton, AB, Canada, 18–22 July 1999; IEEE: Piscataway, NJ, USA, 1999; Volumr 2, pp. 1031–1036
109. Gómez, J.C.; Morcos, M.M. Impact of EV battery chargers on the power quality of distribution systems. *IEEE Trans. Power Deliv.* **2003**, *18*, 975–981. [CrossRef]
110. Guille, C.; Gross, G. Design of a conceptual framework for the V2G implementation. In Proceedings of the 2008 IEEE Energy 2030 Conference, Online, 17–18 November 2008; IEEE: Piscataway, NJ, USA, 2008; pp. 1–3.
111. Andrés, A.L.; Geovanny, M.G.; Camila, P.G.; Hincapié, R.A.; Mauricio, G.E. Optimal charging schedule of electric vehicles considering variation of energy price. In Proceedings of the 2014 IEEE PES Transmission & Distribution Conference and Exposition-Latin America (PES T&D-LA), Medellin, Colombia, 10–13 September 2014; IEEE: Piscataway, NJ, USA, 2014; pp. 1–5.
112. Kütt, L.; Saarijärvi, E.; Lehtonen, M.; Mõlder, H.; Niitsoo, J. A review of the harmonic and unbalance effects in electrical distribution networks due to EV charging. In Proceedings of the 2013 12th International Conference on Environment and Electrical Engineering, Wroclaw, Poland, 5–8 May 2013; IEEE: Piscataway, NJ, USA, 2013; pp. 556–561.

113. Martinenas, S.; Knezović, K.; Marinelli, M. Management of power quality issues in low voltage networks using electric vehicles: Experimental validation. *IEEE Trans. Power Deliv.* **2016**, *32*, 971–979. [CrossRef]
114. Lu, Z.; Qi, J.; Zhang, J.; He, L.; Zhao, H. Modelling dynamic demand response for plug-in hybrid electric vehicles based on real-time charging pricing. *IET Gener. Transm. Distrib.* **2017**, *11*, 228–235. [CrossRef]
115. Outlook, I.G.E. *Scaling-Up the Transition to Electric Mobility*; IEA: Paris, France, 2019.
116. Venegas, F.G.; Petit, M.; Perez, Y. Plug-in behavior of electric vehicles users: Insights from a large-scale trial and impacts for grid integration studies. *ETransportation* **2021**, *10*, 100131. [CrossRef]
117. Streubel, T.; Kattmann, C.; Eisenmann, A.; Rudion, K. Characterization of Supraharmonic Emission from Three Different Electric Vehicle Charging Infrastructures in Time and Frequency Domain. *Energies* **2022**, *15*, 394. [CrossRef]
118. Hoarau, Q.; Perez, Y. Interactions between electric mobility and photovoltaic generation: A review. *Renew. Sustain. Energy Rev.* **2018**, *94*, 510–522. [CrossRef]
119. Sovacool, B.K.; Axsen, J.; Kempton, W. The future promise of vehicle-to-grid (V2G) integration: A sociotechnical review and research agenda. *Annu. Rev. Environ. Resour.* **2017**, *42*, 377–406. [CrossRef]
120. Liu, L.; Kong, F.; Liu, X.; Peng, Y.; Wang, Q. A review on electric vehicles interacting with renewable energy in smart grid. *Renew. Sustain. Energy Rev.* **2015**, *51*, 648–661. [CrossRef]
121. Gu, W.; Yu, H.; Liu, W.; Zhu, J.; Xu, X. Demand response and economic dispatch of power systems considering large-scale plug-in hybrid electric vehicles/electric vehicles (PHEVs/EVs): A review. *Energies* **2013**, *6*, 4394–4417 [CrossRef]
122. Rahman, S.; Khan, I.A.; Khan, A.A.; Mallik, A.; Nadeem, M.F. Comprehensive review & impact analysis of integrating projected electric vehicle charging load to the existing low voltage distribution system. *Renew. Sustain. Energy Rev.* **2022**, *153*, 111756.
123. Ding, Z.; Teng, F.; Sarikprueck, P.; Hu, Z. Technical review on advanced approaches for electric vehicle charging demand management, part ii: Applications in transportation system coordination and infrastructure planning. *IEEE Trans. Ind. Appl.* **2020**, *56*, 5695–5703. [CrossRef]
124. Bhatti, A.R.; Salam, Z.; Aziz, M.J.B.A.; Yee, K.P.; Ashique, R.H. Electric vehicles charging using photovoltaic: Status and technological review. *Renew. Sustain. Energy Rev.* **2016**, *54*, 34–47. [CrossRef]
125. Yilmaz, M.; Krein, P.T. Review of the impact of vehicle-to-grid technologies on distribution systems and utility interfaces. *IEEE Trans. Power Electron.* **2012**, *28*, 5673–5689. [CrossRef]
126. Richardson, D.B. Electric vehicles and the electric grid: A review of modeling approaches, Impacts, and renewable energy integration. *Renew. Sustain. Energy Rev.* **2013**, *19*, 247–254. [CrossRef]
127. Maheshwari, P.; Tambawala, Y.; Nunna, H.K.; Doolla, S. A review on plug-in electric vehicles charging: Standards and impact on distribution system. In Proceedings of the 2014 IEEE International Conference on Power Electronics, Drives and Energy Systems (PEDES), Mumbai, India, 16–19 December 2014; IEEE: Piscataway, NJ, USA, 2014; pp. 1–6.
128. Zhang, X.; Wang, Q.; Xu, G.; Wu, Z. A review of plug-in electric vehicles as distributed energy storages in smart grid. In Proceedings of the IEEE PES Innovative Smart Grid Technologies, Europe, Istanbul, Turkey, 12–15 October 2014; pp. 1–6.
129. Lingfors, D.; Shepero, M.; Good, C.; Bright, J.M.; Widén, J.; Boström, T.; Munkhammar, J. Modelling city scale spatio-temporal solar energy generation and electric vehicle charging load. In Proceedings of the 8th International Workshop on the Integration of Solar Power into Power Systems, Stockholm, Sweden, 16–17 October 2018.
130. El-Bayeh, C.Z.; Alzaareer, K.; Aldaoudeyeh, A.M.I.; Brahmi, B.; Zellagui, M. Charging and discharging strategies of electric vehicles: A survey. *World Electr. Veh. J.* **2021**, *12*, 11. [CrossRef]
131. Tan, K.M.; Ramachandaramurthy, V.K.; Yong, J.Y. Integration of electric vehicles in smart grid: A review on vehicle to grid technologies and optimization techniques. *Renew. Sustain. Energy Rev.* **2016**, *53*, 720–732. [CrossRef]
132. Collin, R.; Miao, Y.; Yokochi, A.; Enjeti, P.; Von Jouanne, A. Advanced electric vehicle fast-charging technologies. *Energies* **2019**, *12*, 1839. [CrossRef]
133. Ahmad, A.; Alam, M.S.; Chabaan, R. A comprehensive review of wireless charging technologies for electric vehicles. *IEEE Trans. Transp. Electrif.* **2017**, *4*, 38–63. [CrossRef]
134. Habib, S.; Kamran, M.; Rashid, U. Impact analysis of vehicle-to-grid technology and charging strategies of electric vehicles on distribution networks—A review. *J. Power Sources* **2015**, *277*, 205–214. [CrossRef]
135. Barone, G.; Buonomano, A.; Calise, F.; Forzano, C.; Palombo, A. Building to vehicle to building concept toward a novel zero energy paradigm: Modelling and case studies. *Renew. Sustain. Energy Rev.* **2019**, *101*, 625–648. [CrossRef]
136. Fachrizal, R.; Shepero, M.; van der Meer, D.; Munkhammar, J.; Widén, J. Smart charging of electric vehicles considering photovoltaic power production and electricity consumption: A review. *ETransportation* **2020**, *4*, 100056. [CrossRef]
137. Mohammad, A.; Zamora, R.; Lie, T.T. Integration of electric vehicles in the distribution network: A review of PV based electric vehicle modelling. *Energies* **2020**, *13*, 4541. [CrossRef]
138. Metais, M.O.; Jouini, O.; Perez, Y.; Berrada, J.; Suomalainen, E. Too much or not enough? Planning electric vehicle charging infrastructure: A review of modeling options. *Renew. Sustain. Energy Rev.* **2022**, *153*, 111719. [CrossRef]
139. Pagany, R.; Camargo, L.R.; Dorner, W. A review of spatial localization methodologies for the electric vehicle charging infrastructure. *Int. J. Sustain. Transp.* **2019**, *13*, 433–449. [CrossRef]
140. Comech, M.P.; Sanz-Osorio, J.F.; Melero, J.J.; García-Izquierdo, O. Impact of the Integration of the Electric Vehicle on Low-Voltage Rural Networks. *Appl. Sci.* **2024**, *14*, 2638. [CrossRef]

141. Safayatullah, M.; Elrais, M.T.; Ghosh, S.; Rezaii, R.; Batarseh, I. A comprehensive review of power converter topologies and control methods for electric vehicle fast charging applications. *IEEE Access* **2022**, *10*, 40753–40793. [CrossRef]
142. Yong, J.Y.; Ramachandaramurthy, V.K.; Tan, K.M.; Mithulananthan, N. A review on the state-of-the-art technologies of electric vehicle, its impacts and prospects. *Renew. Sustain. Energy Rev.* **2015**, *49*, 365–385. [CrossRef]
143. Ashique, R.H.; Salam, Z.; Aziz, M.J.B.A.; Bhatti, A.R. Integrated photovoltaic-grid dc fast charging system for electric vehicle: A review of the architecture and control. *Renew. Sustain. Energy Rev.* **2017**, *69*, 1243–1257. [CrossRef]
144. Escoto, M.; Guerrero, A.; Ghorbani, E.; Juan, A.A. Optimization Challenges in Vehicle-to-Grid (V2G) Systems and Artificial Intelligence Solving Methods. *Appl. Sci.* **2024**, *14*, 5211. [CrossRef]
145. Eltoumi, F.M.; Becherif, M.; Djerdir, A.; Ramadan, H.S. The key issues of electric vehicle charging via hybrid power sources: Techno-economic viability, analysis, and recommendations. *Renew. Sustain. Energy Rev.* **2021**, *138*, 110534. [CrossRef]
146. Aretxabaleta, I.; De Alegria, I.M.; Andreu, J.; Kortabarria, I.; Robles, E. High-voltage stations for electric vehicle fast-charging: Trends, standards, charging modes and comparison of unity power-factor rectifiers. *IEEE Access* **2021**, *9*, 102177–102194. [CrossRef]
147. Haidar, A.M.; Muttaqi, K.M.; Sutanto, D. Technical challenges for electric power industries due to grid-integrated electric vehicles in low voltage distributions: A review. *Energy Convers. Manag.* **2014**, *86*, 689–700. [CrossRef]
148. Hu, J.; Morais, H.; Sousa, T.; Lind, M. Electric vehicle fleet management in smart grids: A review of services, optimization and control aspects. *Renew. Sustain. Energy Rev.* **2016**, *56*, 1207–1226.
149. Thompson, A.W. Economic implications of lithium ion battery degradation for Vehicle-to-Grid (V2X) services. *J. Power Sources* **2018**, *396*, 691–709. [CrossRef]
150. Li, Z.; Khajepour, A.; Song, J. A comprehensive review of the key technologies for pure electric vehicles. *Energy* **2019**, *182*, 824–839. [CrossRef]