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Article

Electric Vehicles: Bibliometric Analysis of the Current State of the Art and Perspectives

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Abstract: In order to gain a comprehensive view of electric vehicles (EVs) technologies and understand the emphasis of current research, this study evaluated the most relevant themes related to EVs through a bibliometric analysis using the keyword "electric vehicle" as the input. The Web of Science^{TM} (WoS) database was used because it is considered ideal for bibliometric analysis. The VOSviewer software was adopted as a bibliometric analysis tool to visualize the networks of authors, countries, journals and keywords. The analysis carried out on 9 November 2021 retrieved a total of 29,304 documents in the period 2000 to 2021. The results show that in the last nine years the number of publications about EVs has grown significantly. The China is the leading nation in the field of EV research, contributing the largest number of publications in the world, with the main authors and research institutions involved. The journal Energies stands out as the main publishing periodical. Keyword analysis showed that studies on EVs in the last two decades have focused on themes related to energy management and storage, infrastructure and charging systems and environmental issues. The bibliometric analysis presented provides relevant information on the main themes studied about EVs and technological advances in development.

Keywords: electric vehicle; bibliometric analysis; VOSviewer

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1. Introduction

In the last years, there has been a significant increase in the purchase of electric vehicles (EVs) on the world market [1]. In 2020, 3 million EVs were sold, surpassing 2019, corresponding to 40% more sales. However, with the COVID-19 pandemic there was a 16% drop in sales, slowing down sales that had been growing for the past 10 years. There are currently more than 10 million EVs registered in the world, and it is expected that by 2050 there will be approximately 300 million EVs in use, corresponding to 60% of new vehicle sales. Data recorded in 2021 indicate strong sales growth in the main automobile markets. This same year (2021) was marked by goals implemented by governments of several countries, the main objective being to reduce to zero by 2050 the emission of greenhouse gases (GHG), with the removal of internal combustion vehicles (ICVs) from the market. Manufacturers from different segments of the automotive industry intend to invest heavily in EVs, aiming to significantly increase this market [2].

The interest in electromobility was mainly due to (i) fossil fuel depletion and subsequent increases in fuel cost [3]; (ii) public awareness and the desire to fight climate change; (iii) the technological advances and commercial effectiveness of renewable energy technologies; (iv) advanced technology of the electric motor and its propulsion systems; and (v) advances in support infrastructure [4]. Many countries and companies have implemented policies and encouraged people to use EVs, and these have facilitated the dissemination and implementation of them in the society [5]. For these reasons, electromobility is considered an effective solution to combat the disadvantages associated with the use of ICVs [6]. Many initiatives have been implemented by policies of various countries. Electromobility gained even more prominence at the Climate Conference (COP21) in December 2015, with the acceptance of the "Paris Declaration on Electromobility and Climate Change and Call to Action". This declaration sets out to reduce global warming by 2 degrees, through "cleaner" and more sustainable transport. For that to happen, EV sales must be around 35% of total vehicle sales by 2030 [7].

Electromobility is an approach aimed at reducing CO_2 emissions and slowing global warming [8,9]. These are the factors that lead to the development and spread of electromobility [10]. However, the development of electromobility can impact the operation of transmission and distribution networks, with occasional peaks in energy consumption [11,12]. One of the reasons for these spikes is that EVs are mostly charged at night. If necessary, energy balancing systems work in low voltage transmission networks, as well as the management of imbalance and technical losses of electrical energy [13]. Another important data point for the development of electromobility is the cost of electricity generation. According to the International Energy Agency (IEA) [14], the costs of generating electricity using a renewable source have been decreasing year after year, getting lower and lower compared to the costs of conventional generation (fossil fuel).

In addition to energy cost, another important parameter considered in the EVs market is the total cost of ownership (TCO). TCO is an estimate of the direct and indirect cost associated with purchasing and maintaining a car [15]. For EVs, this estimate takes into account mainly the price of batteries and fuel cells, as they are fundamental components for the vehicle's total investment costs [16]. In practice, this means that all vehicle expenses must be calculated based on all related costs [17].

Increasing EVs in circulation can reduce transport costs and the effects of greenhouse gas emissions, compared to fossil fuel powered engines in addition to strengthening electric mobility through the high penetration of renewable energy sources [18,19]. It has been reported that the efficiency of the EV is approximately three times greater, in terms of performance, compared to vehicles with an internal combustion engine (ICEVs) [1]. This is in addition to presenting lower maintenance costs, due to their advanced technology, and energy source (electricity) compared to conventional ones (ICVs). On the other hand, batteries are expensive, as they are large and take up considerable space in the vehicle [20]. Despite the numerous advantages of EVs, the acquisition of this technology by consumers has been resisted due to the high purchase price, useful life, and cost of batteries [21]. Another considerable factor is the uncertainty regarding battery life and unavailability of charging infrastructure in some countries [22]. There is much research underway with the aim of increasing the autonomy and efficiency of EVs, directly impacting the price reduction and development of charging systems [23]. Although there are many technologies incorporated into electric vehicles, some challenges must be overcome to establish a green transport sector. One of the main limitations that EVs face today is the lack of charging stations, the charging time of the batteries, and their autonomy [24].

In order to investigate the current state of the art on electric vehicles and to provide guidance on emerging trends in studies related to EVs, a search was carried out in the WoS database and is presented in this work. The goal is to assess sources of publications, articles, journals, authors, countries and institutions, research areas, and the most cited themes about EVs. This paper provides essential information on emerging trends in research involving EVs. It also identifies hotspots that might be interesting as research areas. The rest of the paper is organized as follows: in Section 2 we present the methodology applied to retrieve documents in the WoS database and generate bibliometric networks. Section 3 presents the results and discussion of the data retrieved in WoS. Additionally, Section 4 reviews the literature on the current state of the art and the main perspectives for research involving electric vehicles based on the analysis of keywords.

2. Materials and Methods

Initially, a search was carried out in the WoS database and the evaluation of the obtained documents was divided into three phases (Figure 1): (PHASE 1) definition of search criteria to identify records in the WoS database and refinement of retrieved records (data collection phase); (PHASE 2) the documents were exported to the VOSviewer software for bibliometric analysis of publications, authors, countries, institutions, journals, and areas (data visualization phase); and (PHASE 3) data analysis to identify the main themes discussed in research developed about EVs.

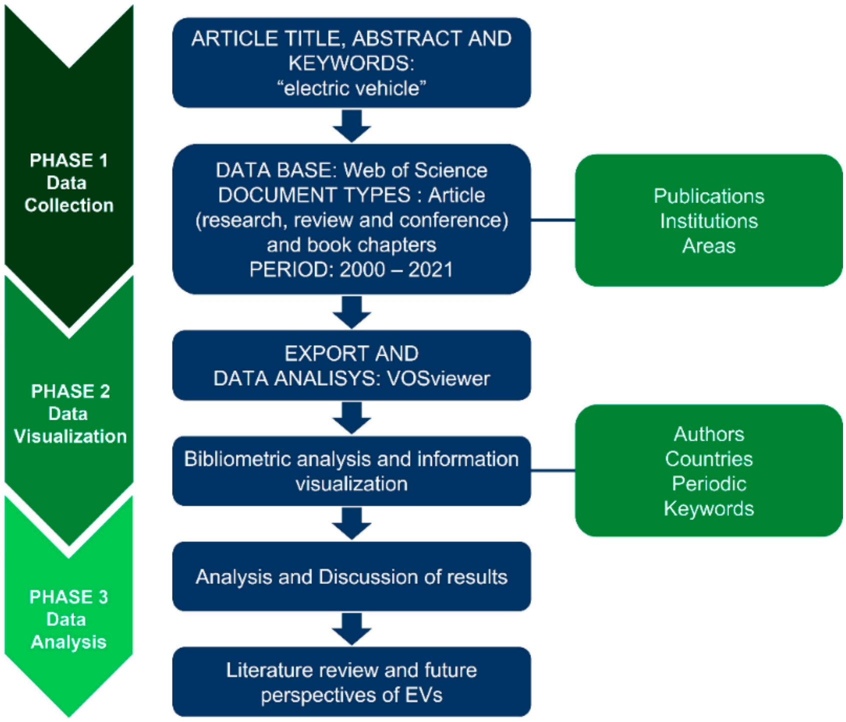

Figure 1. Methodology phases and their main steps and analyzed criteria applied to the present work.

Bibliometrics is an analysis method used to identify scientific trends and systematize research [25], ensuring the quality of information and the production of the results generated [26]. The documents in this study were collected from the WoS data platform, which is considered an ideal database for bibliometric analysis once that cover information published in indexed journals in several areas of knowledge. This database has been widely used in bibliometric analyses [27,28]. The search was carried out on 9 November 2021, using the keyword "electric vehicle" as input. The search period was defined between 2000 and 2021, for a broad analysis of publications. We limited the literature to documents of the article type, being research, conferences, and review. The total number of publications citing the word "electric vehicle" was 29,304. All collected data were exported as files "tab delimited", containing the "Full record and cited references". These data were used for co-authorship and co-occurrence analyses. Thus, it was possible to generate network maps of authors, countries, and keywords. Additionally, from the analysis of citations, the network map of scientific journals was generated.

The software VOSviewer (version 1.6.17, Leiden University, Leiden, The Netherlands) was used for the construction and visualization of bibliometric networks. This software allows extracting information from publications, such as authorship, periodicals, organizations, countries, and keywords. Output results are displayed in interlocking circles for viewing existing connections between bibliometric data [29]. The distance between two or more circles indicates the strength of link between the terms represented by each. Different term groups are represented by different colors. Additionally, the size of the circles is correlated with the frequency of appearance of the terms [30,31]. The number of clusters in each network map can change depending on the number of links. In some cases, terms are not displayed with the label to avoid overlapping. It must be highlighted that repeated or irrelevant terms for this study were manually excluded. Considering the connections between keywords in each cluster, the relevant themes were identified and discussed in detail.

3. Results and Discussion

As already mentioned, the search in the WoS database retrieved 29,304 publications on "electric vehicle" for the period 2000 to 2021. Both the cumulative index and the number of publications show an increase trend in the period investigated (Figure 2). The analysis reveals that between the years 2000 and 2011 there was a slow growth on the number of related EVs publications, and from 2012 on the number increases quite fast, jumping from 662 (2011) to 1149 (2012) presented works. One explanation for this phenomenon is that between 2009 and 2011, incentive policies for the revitalization of the automobile industries were implemented in several countries. Consequently, there was greater interest from researchers on the theme, with the development of EVs and charging systems [25], and since then the publications have increased year by year, and in 2020 it reached 3607 publications. As the 2021 data is still being updated, the number of publications (2833 publications) is still lower compared to 2017, 2018, 2019, and 2020. Nevertheless, the expectation is that after the update the number of publications, the 2020 number will be surpassed by 2021. A fact is that in the last 9 years, the number of publications had an average annual growth of 2574 publications. This indicates that the EV industry is growing, and that research about these related technologies has been gaining strength year after year.

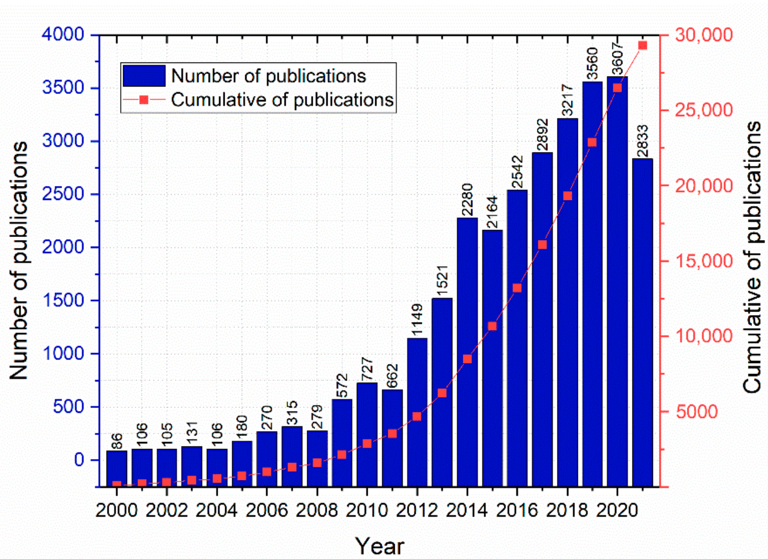

Figure 2. Quantitative distribution of publications in electric vehicle studies, 2000–2021.

In terms of document types, the 29,304 publications are categorized into four categories: (i) conference article (49.26%); (ii) research article (48.37%); and (iii) review article (2.36%). The result reveals that there are still few reviews on the subject, which justifies the development of this presented work.

Regarding author analyses, from a total of 60,053 authors who have published on the theme of electric vehicles, only 3754 (6.25%) have five or more documents linked to their names. The top 10 authors based on the number of citations and documents are presented in Figure 3. The most cited author was Xiaosong Hu with 4817 citations and 60 documents, followed by Minggao Ouyang and Chunting Chris Mi. Xiaosong Hu has been working in research involving modelling and control of alternative motors and energy storage systems. Another interesting fact is that among the ten main authors, eight are linked to Chinese institutions, corresponding to 80%.

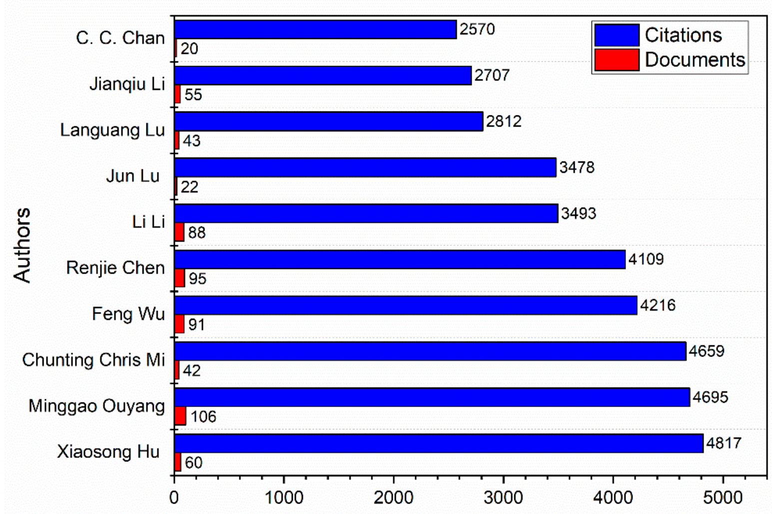

Figure 3. Distribution of the top 10 authors based on the number of citations and documents.

Figure 4 shows a semantic network of published documents by country. As can be seen in the distribution, the People's Republic of China is the country that most publishes about EVs, with the production of 9138 documents (31.18%), followed by the USA with 4843 documents (16.52%) and by India with 1777 documents (6.06%). China's leadership can be explained by the incentives that the government has been promoting since 2005 for studies on and the development of the EV market [32]. These include, for example, subsidies to make the purchase viable, investment in charging stations, parking, and low cost of electricity. All of these incentives resulted in the growth of the EV market in China [33].

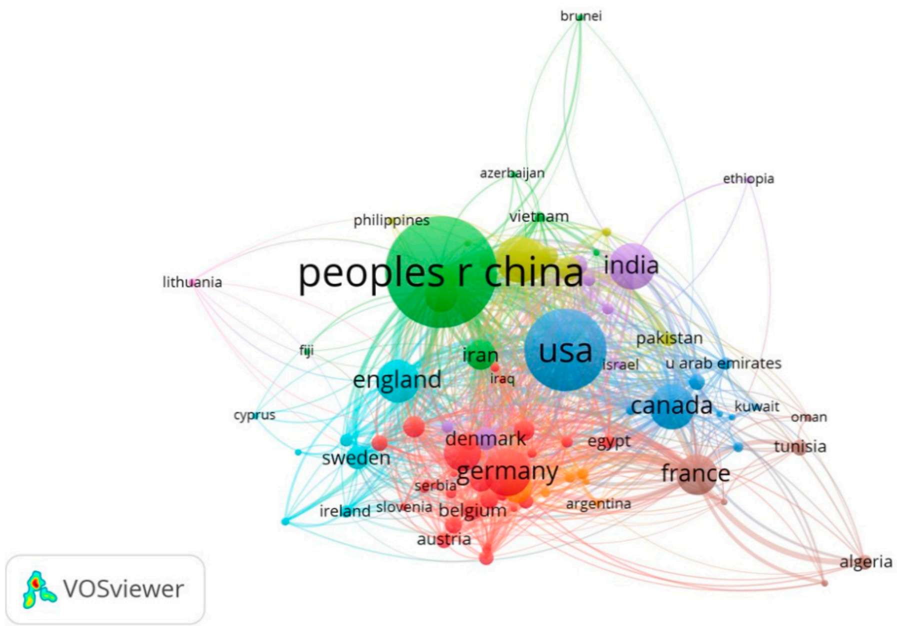

Figure 4. Network visualization of the most productive countries in VEs research output.

In terms of research centers that were involved in the works, this study identified 8690 institutions that participated in the publications. The 10 main institutions with the largest number of documents published on the topic EVs are structured hierarchically in the TreeMap in Figure 5. The size and color represent the separate numerical dimensions of the data. As expected, among the top 10 institutions, five are located in the People's Republic of China. The two institutions that published the most are the Beijing Institute of Technology, with 770 documents (2.62%), and Tsinghua University, with 683 documents (2.32%). They are followed by the United States Department of Energy (DOE) of the USA with 576 documents (1.96%). These data corroborate the results presented in Figure 4.

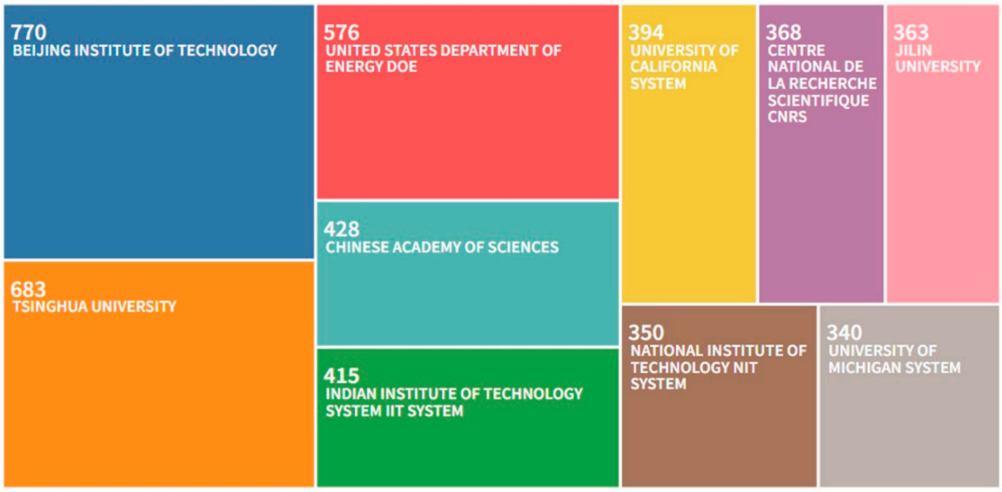

Figure 5. TreeMap of the top 10 institutions that published the most studies on electric vehicles.

Another important aspect to be analyzed is the number of citations of journals to identify key areas of research involving EVs. The documents obtained in this study were published in 5693 different journals; however, only 982 journals have five or more linked documents. The journal Energies (IF. 3.004) stands out for having the largest number of publications on EVs (994 documents), followed by Applied Energy (IF. 9746) (501 documents) and IEEE Transactions on Vehicular Technology (IF. 5978) (482 documents). In general, the main journals on EVs are multidisciplinary or interdisciplinary, involving different areas of research: energy, engineering, transportation, computer science, materials science, electrochemistry, physics, thermodynamics, etc. (Figure 6).

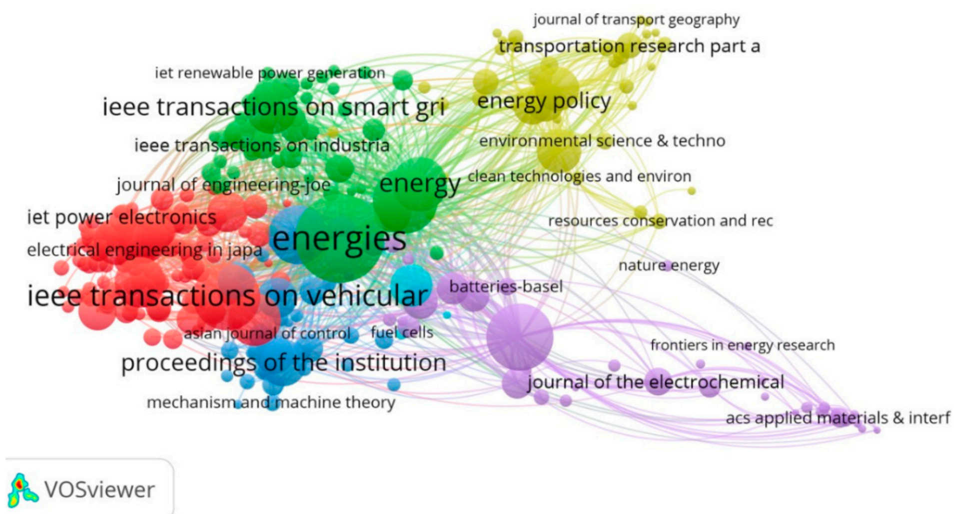

Figure 6. Network visualization of the journals based on total link strength.

Keyword Analysis

In order to verify the scope of work and main themes on research related to EVs, it is important to get inside of each document and extract their main keywords. This analysis is essential to determining trends in emerging themes and identifying hotspots that might be interesting as areas of research, development, and innovation. The analysis of keywords related to EVs generated 53,161 results. Among them, only 4916 (9.24%) reached the limit of at least five co-occurrences (Figure 7).

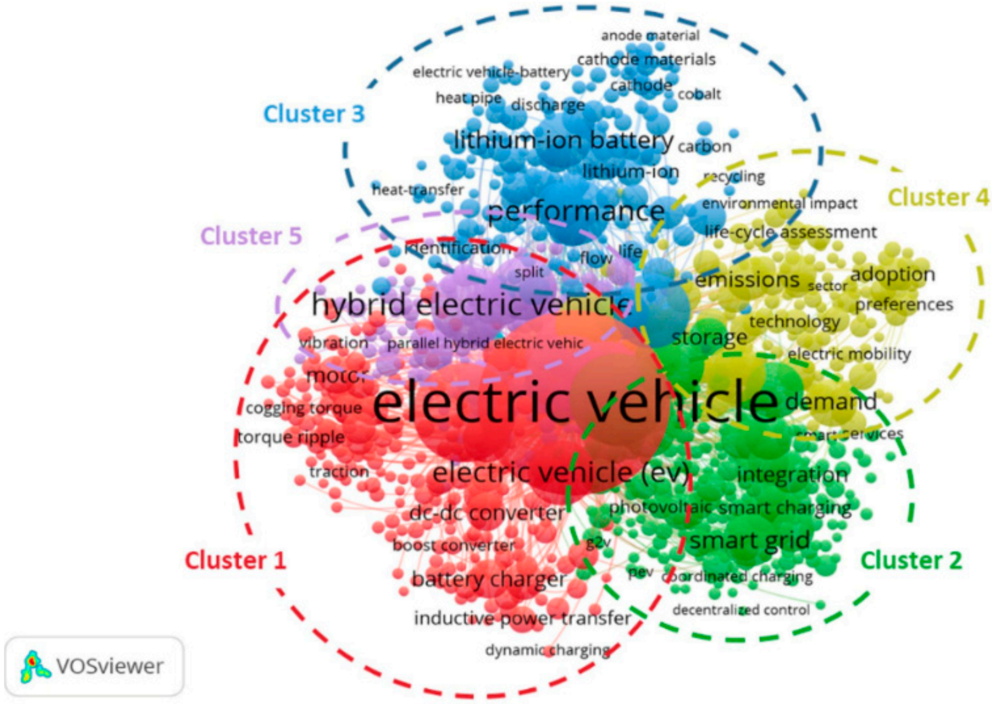

Figure 7. Network visualization of the keywords based on total link strength.

The keywords obtained were classified into five clusters. As expected, the most highlighted term, not only in cluster 1 but also across the entire network, is "electric vehicle". The primary keywords represented in this cluster tend to focus on the EV traction system, such as, motor, traction, cogging torque, and torque ripple. In addition, the focus also covers the battery charging system, for example, DC–DC converters, battery chargers, and inductive power transfer. In cluster 2 the term that stands out is "optimization". The main words in this cluster are related to the vehicle energy management system, such as systems, management, integration, and smart grid. In cluster 3 the highlighted term is "performance" and shows the main words related to the components of the lithium-ion battery, such as cathode materials and anode materials. In cluster 4, the terms related to environmental issues appear more frequently and includes emissions, demand, electric mobility, life-cycle assessment, and environmental impact. Last, in cluster 5, the biggest highlight term is "hybrid electric vehicle".

In terms of technologies and strategies, it is agreed that EVs can be grouped into five categories as highlighted in Figure 8 [23,34–36]:

I. Battery Electric Vehicles (BEVs) are powered 100% by electricity. BEVs consist of an energy storage battery, an electric motor, and a controller. The electric battery can be recharged using energy from the mains by a charger, which can be exclusive to the vehicle or installed in a charging station [37].

II. Hybrid Electric Vehicles (HEVs) have two power units, a conventional internal combustion engine and an electric motor [38]. The HEVs can be series hybrids, parallel hybrids, or power-split hybrids [39]. The HEVs are not loaded into the electrical grid, but through the energy generated in braking, transforming kinetic energy into electrical energy [20].

III. Plug-In Hybrid Electric Vehicles (PHEVs) are composed of an internal combustion engine and an electric motor. PHEVs are gasoline moved and have a large battery that can be charged via an external plug in the electrical network. The difference with HEVs is that they can be connected to the mains [39].

IV. Fuel Cell Electric Vehicles (FCEVs) use electric power train such as BEVs; however, they generate electricity using a fuel cell powered by hydrogen. FCEVs are classified as zero emission vehicles [4].

V. Extended Range Electric Vehicles (EREVs) are equipped with a supplementary internal combustion engine, which charges the vehicle's batteries, if necessary. Unlike PHEVs and HEVs, the engine of EREVs is used for charging only, without connection to the wheels [35].

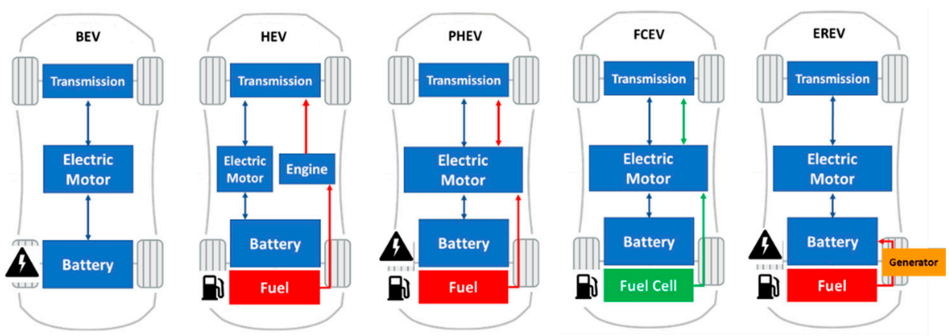

Figure 8. EV types and categories.

Regarding interaction with network and environmental sources, the EVs can work in loading and unloading modes. The different modes of interface with the electrical network are classified as Grid-to-Vehicle (G2V) and Vehicle-to-Grid (V2G), being the last divided into, and Vehicle-to-Home (V2H) and Vehicle-to-Building (V2B) [39,40]. On G2V, the EV is loaded onto the network, while in V2G you have the ability to control the bidirectional flow of electrical energy between a vehicle and the mains at regular intervals [39,41]. The V2H and V2B support residential and building energy use, respectively [42].

During charging mode, the battery is charged from the mains via a rectifier and a converter to regulate the energy between the engine and the battery systems [37]. The function of the DC-AC converter is to activate the traction motors connected on the charging side of the battery. In older EVs, the engines were used to be unidirectional while in recent and modern versions, battery-moved (BEVs), bidirectional DC–AC converters are used in energy storage during regenerative braking. DC–DC converters are a power converter used to convert DC currents. [43]. The electronic power driver is responsible for transferring the charging information between the battery, the converter, and the drive motor. The electronics driver manages the flow of electrical energy from the power battery, ensuring that the correct voltage is supplied [44]. The BEV motor is capable of functioning as a power generator during the deceleration process, charging the battery and, at the same time, exerting torque on the shaft, known as regenerative braking [45]. The energy recovered by the regenerative braking system can reach approximately 15% efficiency [39].

In terms of energy storage, as expected, this system is a key component of EVs. Depending on the technology, this system can have various designs (batteries, ultracapacitors, etc.). Of these technologies, the battery is the most widely used energy storage technology in EVs [46]. The used batteries can be classified based on the different materials used and their applications. Due to the variety of technologies, there are many types of batteries used in EVs for different purposes. The main parameters for classifying and comparing different battery technologies are their performance, energy density, power density, life cycle, and cost per kWh [47].

The battery management system (BMS) performs an important role in EVs. The BMS ensures the security of the energy storage system and evaluates its overall performance, loading/unloading procedures, data acquisition, thermal management, and state of charge (SoC) [48]. Battery SoC estimation is one of the main technologies of EVs and is an important parameter in the BMS. This information contributes directly to the vehicle's performance and reliability and therefore must be carefully monitored with high precision. The SoC provides to the drivers important information about driving range and data evidence to prevent excessive charge and discharging, which may reduce battery life cycle [49]. According to W. Zhou et al. [49], recently there has been a lot of research on battery SoC estimation, which can be divided into three categories: (i) *Direct Measurement Method (not based on battery model)*: the estimate is based on the voltage, current, internal resistance, impedance, and other reproducible variables of the battery parameters that have a significant correlation with the energy; (ii) *SoC Estimation Method Based on the Black Box Battery Model*: for this model the battery is an unknown system. This method considers the measurable battery current, voltage, temperature, etc., as the model input and the battery SoC as the model output; and (iii) *SoC Estimation Method Based on the State Space Battery Model*: it is based on the battery model to estimate the state of the system. This model connects variables such as current, voltage, temperature, and other measurements with the SoC from a "filter" or "observer" that estimated its value. Laadjal and Cardoso [50], claim that methods for estimating SoC are necessary for the efficient, sustainable, and safe operation of battery-powered devices.

Currently, lithium-ion batteries are the most applied technology in EVs [51,52]. Lithium-ion batteries have high energy density, high power and efficiency, long life cycle, low discharge rate, and high voltage [53]. However, those batteries have some disadvantages, such as low autonomy, long charging times, a high cost, and problems with safety and reliability [20,54]. Additionally, they are quite sensitive to extreme temperatures during operation [55,56], which may occur due to high charging current conditions, such as rapid charging or accelerations and consequently a sharp rise in temperature [57]. At high temperatures (>35 °C), electrochemical reactions can be intensified, generating heat and causing capacity weakening and aging [56,58]. Overheating can result in combustion, explosion, or even in the escape of toxic gases, bringing great attention to the safety of EVs [59]. At low temperatures (<15 °C), there is a reduction in chemical kinetics and, consequently, an increase in internal resistance, which reduces the battery's discharge capacity [60]. The internal resistance increases due to a decrease in the rate of the diffusion of ions into the electrolyte and an increase in the viscosity of the electrolyte. This behavior can cause internal short circuits [55,61,62].

Generally, it is difficult to control the temperature change of batteries, mainly because they are affected by external factors (weather conditions) and exothermic reactions during charging and discharging [63]. Furthermore, EV users are still not satisfied with the performance of the current driving range. The expectation is that the performance of the EVs could approach or reach the driving range level of the ICEVs. In order to maximize the performance of EVs, manufacturers tend to place more batteries in a drive space to increase the driving range. However, this may further compromise the exothermic problem of batteries [64]. Therefore, the global research and design development of efficient battery thermal management systems (BTMS) are essential to ensure that the battery temperature remains in the desired range, minimizing battery temperature non-uniformity as much as possible [65–67].

To overcome these disadvantages, Komsiyska et al. [54] highlighted the Intelligent Battery Systems (IBSs) as a promising and challenging technology. IBSs promise to increase the reliability, safety, and efficiency of BEVs. These systems are composed of advanced monitoring sensors at the cell level, responsible for reversibly modifying any system inconsistencies. Despite existing gaps, IBSs can overcome limitations and problems that exist in conventional battery systems [54].

Liang et al. [64] proposed the integrated thermal management system (ITMS), with the integration of battery thermal management systems (BTMS), an engine cooling system, and air conditioning. The objective is to recover the residual heat from batteries and motors, optimizing energy efficiency. This is a solution that can be effective in increasing the autonomy of EVs with the existing technology. However, the ITMS still has some bottlenecks, such as the system being quite complex, the cold/heat distribution problem, and the need to optimize the system structure and improve the control algorithm.

In recent years, many researchers have focused on the development of advanced battery systems due to the high demand for alternative secondary batteries. Motivated by the availability of raw materials, new energy storage systems with a high charge density and safety using advanced materials are under development [68].

According to Sanguesa et al. [20], the search for improvements in terms of durability, charge density, and charge and discharge processes has promoted the use of multiple resources in the development of new technologies capable of surpassing current lithium-ion batteries. Currently, new technologies and components are being researched, including lithium iron phosphate ($LiFePO_4$), magnesium ion, lithium-metal, lithium-air (Li-air), aluminum-air, sodium-air (Na_2O_2), and graphene. They report that there is still a gap in this field, and that battery upgrades can accelerate the success of EVs and the worldwide deployment of these vehicles remarkably. It is expected that in the coming years with the development and combination of new materials, energy storage systems will be improved [47].

In addition to the energy storage system, the charging system is another challenge for the EV industry. Charging technology is critical and plays an important role in the electromobility sector. Alongside the energy storage system, they are responsible for releasing the "range anxiety" of the EV drivers. With technological advances and investments in charging infrastructure, the charging process is becoming faster and more accessible [69]. For EVs to have definitive success, it will be necessary for users to charge their vehicles quickly and simply [20].

There are different modes of energy transfer, and battery charging for EVs can be classified as conductive charging, inductive charging, and battery change [70]. The conductive mode is based on the charge transfer method through the direct contact between the EV and the charge port with the help of a cable. This type of charger is considered the most efficient way to transfer energy with minimal losses [71]. Inductive charging does not use cable; the battery is charged from an electromagnetic field to transmit energy between an outlet and the EV [72]. Due to the flexibility that wireless charging offers, the EV charging process can also occur during temporary stops or even while driving, thus allowing, a reduced power capacity for the batteries [73]. The Wireless Power Transfer (WPT) is a wireless charging method and stands out as futuristic technology with the advantage of flexibility, convenience, and safety and the capacity to become fully automated in addition to its high efficiency and easy maintenance [74].

The main charging technologies that are currently in development [75,76] are: (i) solar-powered charging; (ii) battery energy storage system (BESS); (iii) battery swapping system/station (BSS); (iv) pantograph charging; and (v) smart charging.

Charging with solar energy is based on the conductive mode, and the DC input source for the integrated charger is via PV modules connected directly via cable. The positive point of this system is the unidirectional energy flow (G2V) and the cost of electricity supply [77]. The negative point is that it is only applicable for DC charging and can only charge during the day [75].

BESS can store electricity from renewable sources such as solar, wind, etc. and provide energy at night or non-solar periods. BESS is a clean energy source and can provide energy during the day and night. The disadvantages are the high initial cost and its size [78].

In BSS the depleted battery is replaced by a fully charged battery, automatically. The advantages of BSS are the short change time and recharge time during off-peak hours [79], and the disadvantages are the additional battery costs and the expensive exchange system (use of automated systems) [4].

Pantograph charging is a conductive charging mode, that allows the charging of heavy electric vehicles such as buses, trucks, etc. Charging is carried out on top of the vehicles, where the batteries are located. The advantages of pantograph charging are the use of a single charge current collector and high-power transfer levels, being fully automated, and the robust design. Disadvantages are the high initial cost and being applicable only to high power DC charging, specifically for charging heavy EVs [75].

Smart charging uses artificial intelligence to enhance the charging station's capabilities. This can be used for automatic charging systems. This system can also be optimized according to different situations, increasing the efficiency of the process [76].

The autonomy of EVs and charging infrastructure are two limiting factors that consumers consider essential for the purchase of this type of transport. Studies have shown that consumers are avoiding the adoption of EVs due to the lack of public charging stations [80]. For this, it is essential to implement adequate infrastructure, thus enabling the fast charging of vehicles [20]. Thus, planning and managing the charging station operation is crucial to increasing the profit and success of the EV charging station [81]. The planning stage is a process of debates that involves decision-making at various levels, such as charging level, number of charges, space requirement, and charging station type. Charging stations must be installed in ideal locations so that they can meet the needs of EV users while keeping all parameters under control [71,82].

Environmental issues such as the continued depletion of fossil fuels, air pollution, and global heating, have attracted more and more attention in recent decades [83]. EVs have the potential to reduce these emissions due to greater efficiency, along with the possibility of being powered by renewable energy [84]. The main environmental advantages of EVs are zero particulate emission from the exhaust pipe, and nitrogen oxide gases (NOx) and sulfur oxides (SOx) and a reduction in dependence on fossil fuels compared to ICEVs [85].

The production of smart grid power supplies assisted by artificial intelligence is an important means of steady growth in the automotive industry, reducing fossil fuel consumption and environmental degradation. These technological advances keep increasing the importance of EVs, mainly in the control of global warming and energy stability [86,87].

4. Conclusions and Future Perspectives

This study provides an overview of the main themes related to EVs that have been researched in recent years. The trend is a sustainable growth of publications annually related to EVs, which indicates that this theme has been gaining more and more interest. The People's Republic of China currently stands out as the country with the most publications on the theme of EVs, corresponding to 31.18% of publications in the world, in addition to having the author with the highest number of publications and citations, Ph.D. Xiaosong Hu. The five most referenced institutions in the publications are also located in People's Republic of China. The journal Energies is the main journal of publishing in the field. In general, the main journals that publish studies on EVs are multidisciplinary or interdisciplinary.

Based on the analysis of the most cited keywords, we identified that the energy storage system is one of the main themes currently being studied in EVs. Researchers are focused on optimizing the battery management system and thus improving temperature distribution. For this, new technologies have been developed, such as IBSs and ITMS in addition to the study of new materials applied to the main components of the battery. Another challenge is the charging systems. With the increase in the worldwide fleet of EVs, new charging systems are under development. The highlight is on inductive charging methods, as WPT is the technology of the future, and many studies have used this method as a foundation.

EVs are already a reality, and their future is promising. Several governments have supported the implementation of electric transport, leading practically all automakers to invest in VEs projects. The results of this study suggest that the energy storage and management system, as well the storage infrastructure deserve further investigation, for example in

(i) EV performance improvements, mainly in the energy storage system, increasing your autonomy and security; (ii) charging system optimization, providing faster and simpler charging; and (iii) expansion of charging networks, to meet the demands of EVs. Therefore, it is necessary to intensify R&D efforts to overcome the technological and economic challenges related to EVs. This intensification can be driven by the fulfillment of the Paris climate agreement goals and sustainable development goals by the United Nations. The agreement's objective is to reduce global warming with the control of greenhouse gas emissions, accessibility to clean energy, inclusive economic growth, sustainable cities, and responsible consumption and production.

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Abbreviations

EV	Electric Vehicle
WoS	Web of Science
GHG	Greenhouse Gases
TCO	Total Cost of Ownership
ICEV	Internal Combustion Engine Vehicle
BEV	Battery Electric Vehicle
HEV	Hybrid Electric Vehicle
PHEV	Plug-In Hybrid Electric Vehicle
FCEV	Fuel Cell Electric Vehicle
EREV	Extended Range Electric Vehicle
G2V	Grid-to-Vehicle
V2G	Vehicle-to-Grid
V2H	Vehicle-to-Home
V2B	Vehicle-to-Building
kWh	kilowatt-hour
BMS	Battery Management System

SoC	State of Charge
IBS	Intelligent Battery Systems
ITMS	Integrated Thermal Management System
BTMS	Battery Thermal Management Systems
WPT	Wireless Power Transfer
BESS	Battery energy storage system
BSS	Battery swapping system/station

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