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Abstract

Electric vehicles (EVs) are a strategic solution to environmental challenges, combining energy efficiency and reduced emissions. This study conducts a bibliometric analysis and technological mapping of the sector, comparing Brazil's position with leaders such as China, the United States, and Germany. The objective is to identify trends in national development. The methodology includes data from bibliographic and patent databases, analyzing scientific publications and technological records. The results show that China leads in batteries and infrastructure, while Brazil demonstrates low scientific production and reliance on foreign technology. Despite its renewable energy matrix and programs such as Rota 2030, integrated policies for innovation are lacking. It is concluded that Brazil needs to strengthen its scientific research, integrate academia with the productive sector, and invest in infrastructure to compete in the global electric vehicle market.
Keywords: Electric vehicles, Bibliometrics, Technological mapping.

1 Introduction

Electric vehicles (EVs) have been seen as one of the solutions to tackle the environmental challenges of the 21st century. Concern about climate change and the need to reduce global dependence on fossil fuels have driven significant investments in clean technologies, with EVs playing a key role in this scenario. In addition to featuring reduced or zero emissions during operation, these vehicles stand out for their energy efficiency, making them major strategies for sustainable mobility (Ferreira & Silva, 2024).

However, the adoption of EVs does not occur uniformly across the world. Countries such as China, the United States, and Germany lead both in scientific production and patent registrations, establishing themselves as key players in the development and commercialization of technologies associated with these vehicles. These advancements reflect significant investments in research, charging infrastructure and integrated public policies. On the other hand, Brazil, despite having a renewable energy matrix and significant technological potential, faces structural and innovation barriers, such as dependence on imported technologies and a lack of integration between academia and the productive sector (Diniz, 2024).

This article aims to contribute to the understanding of these dynamics through a bibliometric analysis and technological mapping of the EV sector, using data from scientific publications and patents. The objective is to compare Brazil with global leaders, identifying national development in the sector.

Although Brazil is a country with energy potential and experience in alternative technologies such as ethanol, it still faces challenges in positioning itself competitively in the electric vehicle market (Pagel, Campos & Carolino, 2018). Issues such as dependence on foreign technology and the lack of technological mapping raise questions about how the country can align with global strategies and drive local development. Thus, this study aims to understand and reflect on: Why does Brazil have a low level of scientific and technological production on the topic of electric cars, despite favorable energy potential conditions?

The relevance of this research lies in its contribution to understanding the scientific and technological landscape of electric vehicles, particularly in the Brazilian context. Bibliometric indicators and technological mapping are tools that assist in understanding Brazil's position compared to other countries, such as China and the United States, which lead this market.

With the growing demand for sustainable mobility solutions, it is imperative for Brazil to develop its technological capacity, ensuring greater independence and competitiveness in the international electric vehicle market.

2 Contextualization

Electric vehicles are one of the technologies aimed at greater efficiency for the energy transition, representing a response to the demands for sustainability in the transportation sector. Studies show that while internal combustion engines convert only about 30% of energy into motion, EVs achieve efficiencies exceeding 90%, highlighting their energy superiority (Faller & Masiero Junior, 2019; Leite, 2021; Schiavi, 2020). Furthermore, the reduction of emissions, particularly in countries with renewable energy matrices, positions EVs as a potential solution to climate change.

The advancement of EVs is linked to global Research and Development (R&D). Countries such as China lead both in scientific publications and patent filings, reflecting government strategies to promote innovation. Bibliometric analysis shows that the most researched areas include batteries, charging infrastructure, and integration with renewable energy, all of which are essential for the future of EVs (Schiavi, 2020). In contrast, Brazil shows modest growth, with scientific production focused on alternative energies such as biofuels, and a patent volume dominated by foreign companies such as Toyota.

Despite having an energy matrix predominantly composed of renewables, Brazil has yet to fully explore its potential in the EV market. The reliance on imported technologies, combined with the lack of charging infrastructure and specific incentives for R&D, limits the country's competitiveness (Schiavi, 2020). Public policies such as Rota 2030 represent initial progress but still lack greater integration with market and academic demands (Brasil, 2020).

Thus, bibliometric indicators are important tools for understanding the scientific and technological landscape. Through the analysis of databases such as Web of Science (WoS) and Derwent Innovation Index (DII), it is possible to identify trends, key players, and gaps in the development of EVs. By integrating bibliometric analyses and technological mapping, this article aims to provide a comprehensive overview of the sector's dynamics, proposing strategies to enhance Brazil's role in the global electric vehicle market.

3 Methodology

The article is based on a quantitative approach as it develops metric processes involving bibliometrics, database searches, and their quantification, with bibliometric analysis providing insights into the scientific production of electric vehicles globally and in Brazil, focusing on patent analysis and technological innovation.

Data collection was one of the most important stages of the process, as it gathers extensive information and relies on a well-structured and defined step-by-step approach to achieve the expected results. To this end, searches were conducted using the Web of Science (WoS) database, the Brazilian Digital Library of Theses and Dissertations (BDTD), and the Derwent Innovation Index (DII) patent database, as they are relevant and globally comprehensive. There was no restriction on the initial year for data collection, as the aim of this research was to analyze the evolution of this type of technology in academic research and technology registration.

The organization of data into charts and tables was performed in Excel spreadsheets to facilitate understanding and highlight patterns. The definition of search terms and the retrieval of data related to scientific publications and patents were analyzed by experts in the field, and the results of the collection are presented in Table 1:

Table 1 – Number of Data Collected from Databases

DATABASE	*WOS*	*DII*
Number of Documents	106,453	189,310

Source: Prepared by the authors

For a more precise analysis and with the aim of mapping Brazil, in some cases the search was maintained to include all countries, but the focus was on restricting the search to the country. Based on the collected data, the Vantage Point software was used as the tool to assist in counting, standardizing, and organizing the data retrieved from the database.

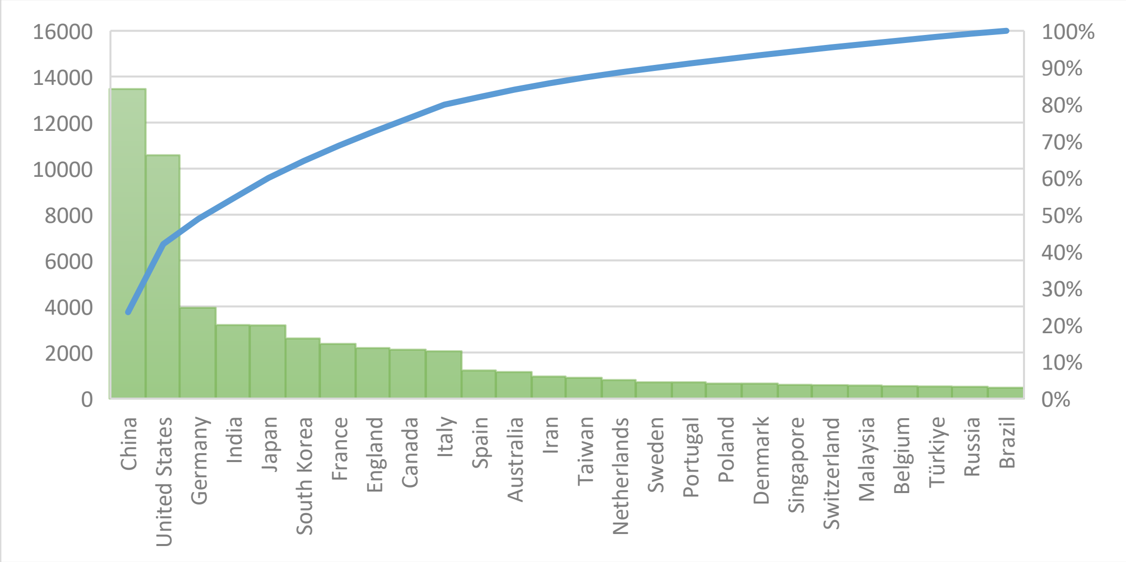
4 Scientific Production on Electric Vehicles

Global advancements and academic institutions play an important role in the continuous growth process, and scientific production contributes to the dissemination of knowledge within society. The increase in the number of published articles and scientific documents is a reflection of this importance. Studies such as Klebis (2018), based on the National Science Foundation (NSF), report that research efforts have intensified, particularly in developing countries that invest heavily in science and technology.

The author (Klebis, 2018) further points out that the United States, as a global power, stands out for producing high-quality and impactful research. However, China's growth in the scientific landscape has become evident, positioning the country as a leader in the volume of scientific production. This prominence is driven by significant and ongoing investments, particularly in fields such as science and technology.

This scenario highlights the importance of fostering research and disseminating its results as a strategy to promote social development. Some countries, such as China, have excelled in the number of publications related to electric vehicles. Data extracted from the Web of Science (WoS) confirm that China leads globally in scientific productions on the topic, as illustrated in Graph 1.

Graph 1 - Countries with the Highest Number of Scientific Publications (1953 to 2019)



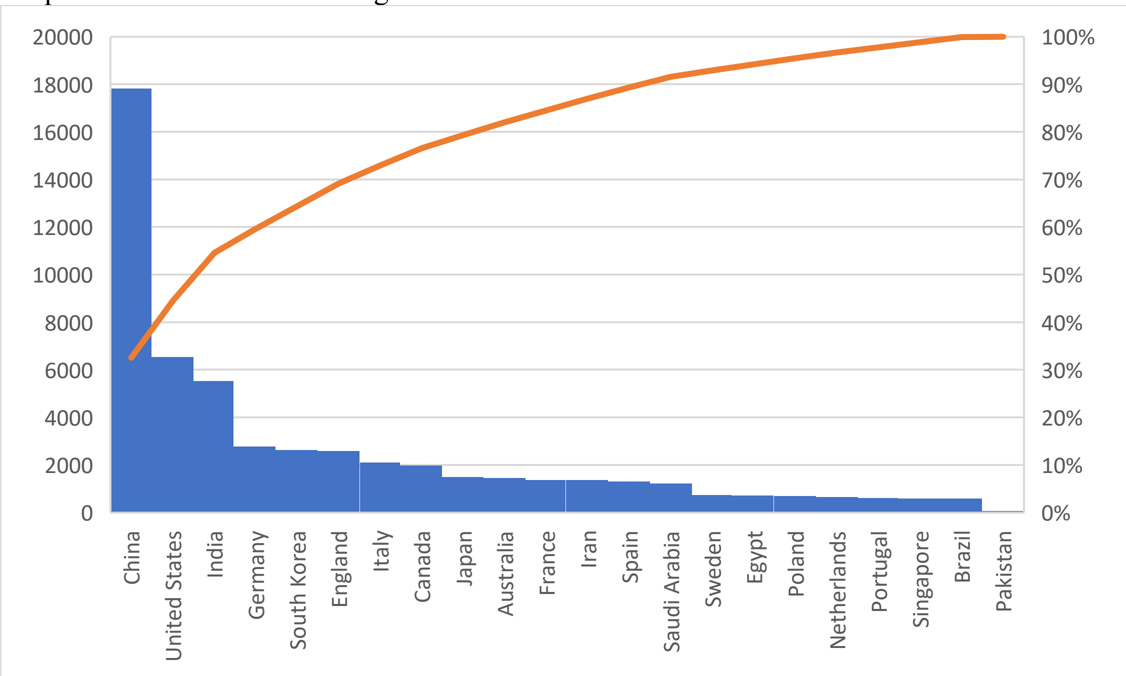
Source: Schiavi (2020). Data collected from WoS. Graph prepared by the authors.

In this initial collection, the analysis of publications was conducted up to 2019 (the year of the first data collection and analysis), showing China's dominance in scientific production on the topic of electric vehicles. China, recognized as a global power in scientific publications, leads the field with approximately 13,500 records, standing out due to its leadership position, likely linked to policies promoting technological innovation, government investments in research and development (R&D), and its strategic focus on fleet electrification, aligned with energy sustainability goals (IEA, 2024). Next, the United States ranks second with approximately 10,600 publications, followed by Germany with nearly 4,000 publications. Both the United States and Germany invest in innovation and have advanced research infrastructure. In the United States, companies like Tesla and federal initiatives drive these efforts. Germany, on the other hand, combines academic research with the automotive industry, as highlighted by studies from Bohnsack, Ciulli & Kolk (2021).

Brazil, in turn, ranks 25th, with approximately 470 publications. Despite the growing interest in electric vehicles, Brazil stands out with its unique ethanol technology, developed through a national program that provides a sustainable alternative to gasoline, making it the only country in the world to master this technology. However, the country faces structural and financial barriers to establishing electric vehicle infrastructure. Studies such as Schiavi (2020) suggest that the country needs greater alignment between academia, government, and the private sector.

By conducting a second analysis, focusing on the years when the growing electric vehicle (EV) market expanded, from 2020 to 2024, it was noted that there was a significant increase in scientific production on electric vehicles (EVs) compared to the initial period analyzed in the first graph (Graph 1) and the more recent period shown in Graph 2:

Graph 2 - Countries with the Highest Number of Scientific Publications from 2020 to 2024



Source: Data collected from WoS. Table prepared by the authors.

In both graphs, China maintains a prominent position, but in the second graph, an even more pronounced growth is observed, reaching 17,813 publications between 2020 and 2024. This reinforces the continuity and intensification of investments in research and development in the EV sector. The increase compared to the first graph also shows a significant acceleration, with China expanding its number of scientific publications and further distancing itself from other countries.

The United States, while remaining in second place, shows more pronounced growth in the recent period, reaching 6,545 publications. This pace of publications may indicate a lower priority compared to China but, at the same time, could reflect a cautious approach to the topics addressed in its publications, as previously mentioned, given that the United States values quality and high impact in its scientific output.

Unlike in Graph 1, India emerges as a new country that has stood out over the past four years, surpassing Germany and South Korea to take third place in the most recent period, with 5,520 publications. This advancement is possibly linked to government policies that promote electrification and technological innovation in the country.

Countries like Japan and Germany show relatively stable positions or more modest growth, which may indicate structural or strategic challenges in expanding their EV research.

In the case of Brazil, its position remains very low in both periods, reaching only 580 publications in the most recent period, indicating a still disjointed and underfunded academic market. Graph 2 also highlights the emergence of new countries, such as Saudi Arabia, Egypt, and Pakistan, which were not present in Graph 1. These countries may be beginning to integrate strategies aimed at innovation and sustainable development, with a focus on EVs.

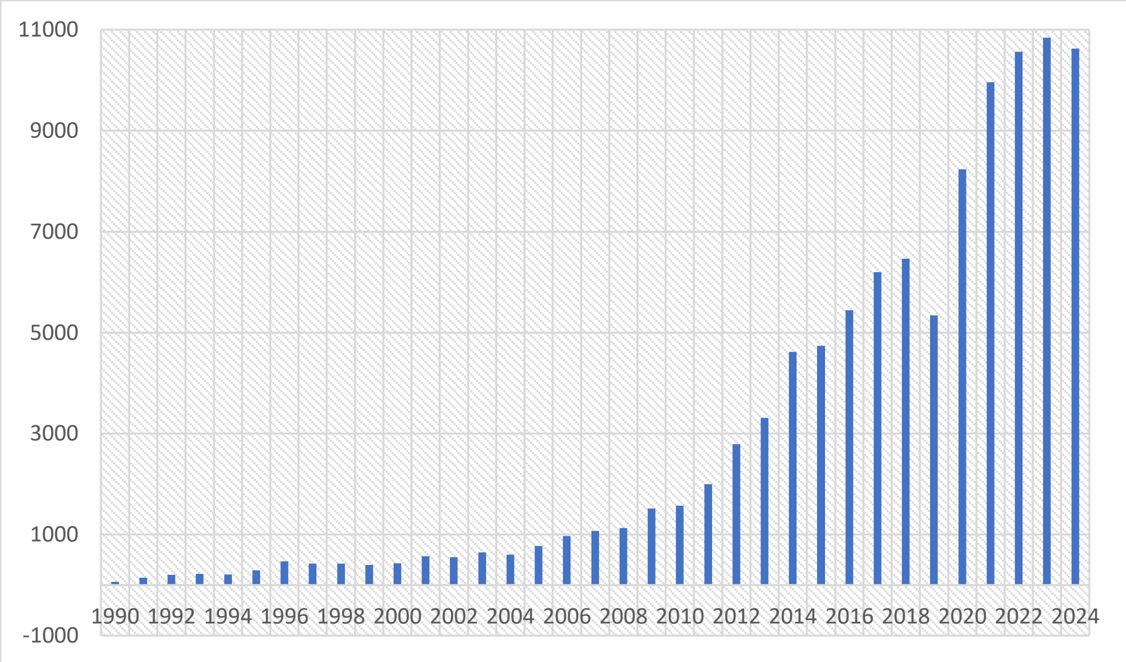
Both graphs show that the global research landscape on electric vehicles is dominated by countries with strong government strategies and investments in science and technology, such as China. Additionally, new players like India and Saudi Arabia are gaining ground, which could lead to increased international competition in the field. In Brazil, the slow pace of publications underscores the need for greater integration between academia, government, and industry to boost its competitiveness in this strategic sector.

4.1 Importance of Scientific Production on Electric Vehicles

The electric vehicle has increasingly gained prominence in the market, driving the growth of a country in this sector. The analysis of the Web of Science (WoS) database highlights the significant growth in publications related to the topic, indicating that it is a promising market poised to stand out in the coming years.

The data collected from the WoS database show that, starting in the year 2000, there was an intensification of scientific and technological interest in electric vehicles, with advancements in research on batteries, charging infrastructure, and integration with renewable energy sources. As shown in Graph 3, the increase in publications reflects the growing importance of electric vehicles as a sustainable transportation solution, aligning with the demands for innovations in the sector.

Graph 3 - Evolution of the Number of Scientific Publications on Electric Vehicles in the WoS Database



Source: Data collected from WoS. Table prepared by the authors.

From the year 2000 onwards, scientific publications on electric vehicles began to grow significantly, as evidenced by the analysis of the WoS database. During the earlier period, between the 1950s and 1990s, interest was limited, although concerns about environmental issues, such as global pollution and CO2 emissions, were already present, as previously mentioned, along with attempts to develop electric and hybrid vehicles in some countries, such as the United States. However, technical challenges, such as low range and reduced speed of the initial models, hindered their popularization (Goldemberg, Lebensztajn & Pellini, 2018).

During this period, development programs focused on electric vehicles began to emerge, encouraging research on topics such as battery cost and efficiency, the most suitable types of batteries, and the environmental impact of thermoelectric plants. These advancements stimulated the evolution of the sector (Goldemberg, Lebensztajn & Pellini, 2018).

The analysis shows that from the year 2000 onwards, there was a significant increase in the number of scientific publications on electric cars. Between 2000 and 2005, publications increased from 433 to 775, representing a growth of nearly 79%. This reflects the growing relevance of the topic, driven by factors such as favorable legislation, environmental concerns, and the pursuit of cleaner technologies. The landscape has shifted, with electric vehicles gaining traction in the global market. Technologies such as embedded systems, high-efficiency converters, and high-energy-density batteries began to revolutionize the sector (Goldemberg, Lebensztajn & Pellini, 2018).

The growth of EVs became more significant in the 2010s. In 2010, there were 1,574 scientific publications, and by 2020, this number had jumped to 8,237, representing an increase of over 423% in just one decade. This advancement may be associated with the consolidation of electric vehicles as a viable alternative to internal combustion models and the progress of technologies such as high-energy-density batteries and embedded systems.

The significant growth starting in 2017, as evidenced by the data (6,199 publications in 2017 to 8,237 in 2020), reflects a period when electric vehicles began to gain greater traction in the global market, alongside technological advancements and reductions in production costs, particularly for batteries.

The period of highest scientific production was recorded in 2021 and 2022, with 9,958 and 10,564 publications, respectively. This reflects the growing interest in both academic research and the market, with electric vehicles gaining prominence in discussions about sustainability, megacities, and energy transition.

Despite the peak, the data for 2023 and 2024 indicate a slight stabilization, with 10,840 and 10,623 publications, respectively. This suggests that, although the topic remains prominent, it may be entering a phase of maturity in the scientific field and in the evolution of research within the automotive sector regarding electric vehicles.

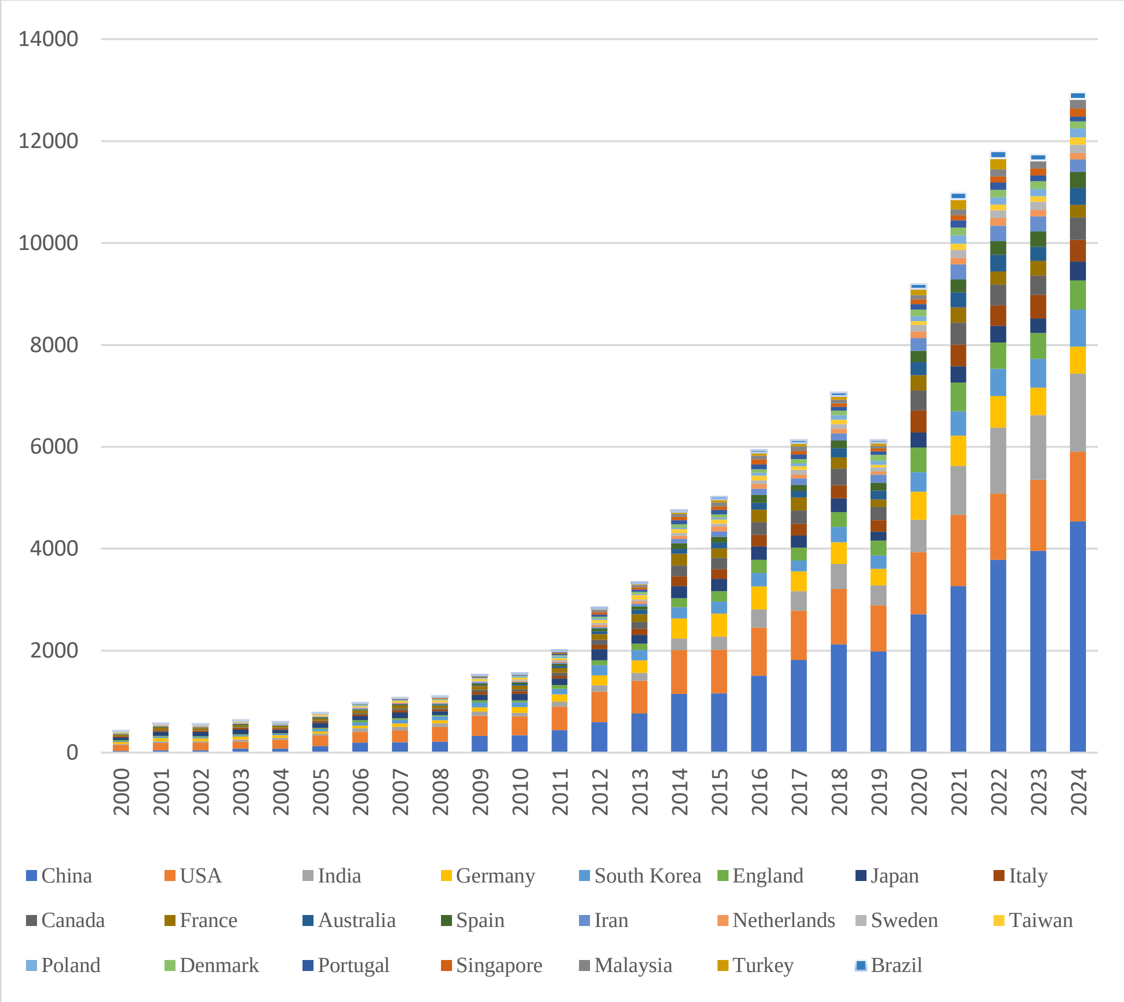
4.2 Evolution of Research on Electric Vehicles

In recent decades, interest in the topic of electric cars has intensified, reflecting changes in the global industrial, environmental, and economic landscape. According to König et al. (2021), Santos et al. (2024), and Reis & Pegado (2024), the advancement of electric propulsion technologies and the pursuit of sustainable transportation solutions have driven a wide range of studies focused on battery development, charging systems, and associated environmental impacts. Similarly, authors such as Borenstein & Davis (2024) highlight that public policies, particularly subsidies for electric vehicles and emission reduction targets, have played an important role in fostering scientific research and implementing innovative solutions in various countries.

These dynamics are influenced by the role of nations in funding and promoting research on electric vehicles. According to Islam et al. (2023), countries such as China and the United States have led academic and technological production, largely due to government strategies that combine tax incentives, support for charging infrastructure, and ambitious fleet electrification targets. This combination of factors has fostered not only technological advancement but also a scenario of international scientific collaboration, as reflected in the publication data over the years.

Graph 4 illustrates the global growth in publications on electric cars, highlighting the distribution by country and the periods of intensified research activity.

Graph 4 - Year of Publication by Country in the WoS Database



Source: Data collected from WoS. Graph prepared by the authors.

The analysis of Graph 4 confirms the trends discussed earlier. The initial leadership of the United States, with publications dating back to 1967, is a direct reflection of its pioneering investment in the automotive industry and electrification technologies. These efforts may have been driven, in part, by oil crises and environmental pressures. On the other hand, the delay in publications from countries like China, India, and Brazil highlights the time required to establish their industrial and scientific foundations in the electric vehicle sector.

From 2010 onward, a greater democratization of scientific knowledge on the topic is observed, with a significant increase in publications in various countries, such as South Korea, France, and Canada. This reflects the globalization of scientific research and the competition among nations to lead the electric vehicle market, whether from an economic or environmental perspective. This scenario also highlights the role of public policies and government incentive programs, which were crucial in boosting the number of studies, particularly in nations like China and India.

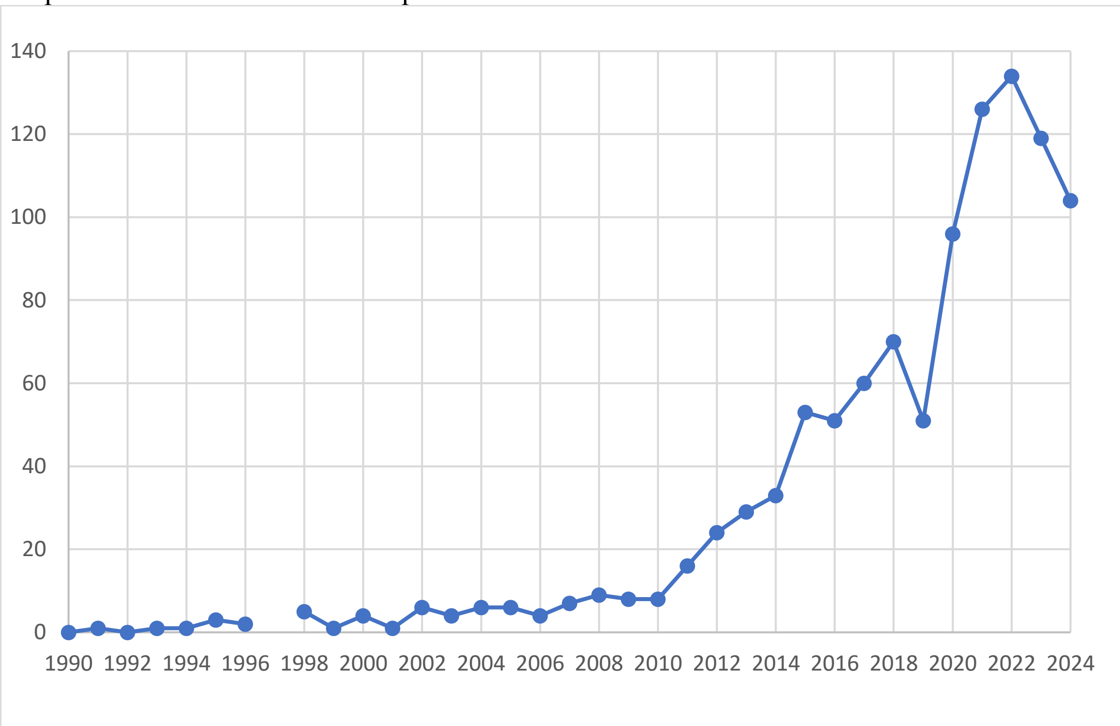
Therefore, Graph 4 demonstrates how scientific dynamics align with industrial and political development, and how the challenges in the transportation sector encourage global cooperation and knowledge exchange on issues such as sustainability and energy efficiency.

4.3 Scientific Productions in Brazil on Electric Vehicles

In Brazil, the advancement of scientific research on electric vehicles (EVs) is directly linked to global changes and internal demands for technological innovation and sustainability. In recent years, national scientific production on the topic has followed international growth, driven by scientific events, public incentive policies, and international collaborations. According to Araújo & Tsai (2024), Brazil, despite facing structural challenges, stands out in research initiatives related to transportation electrification, focusing on issues such as energy efficiency and the use of complementary biofuels.

The first publication indexed in the WoS database in Brazil was in 1991, by the University of São Paulo (USP) in the city of São Carlos. This publication explored the properties of electric transportation in the fields of Physics and Mathematical Science. In that year, only one publication was recorded. However, over the years, the number of studies gradually began to increase, as illustrated in Graph 5.

Graph 5 - Growth of Publications per Year in the WoS Database



Source: Data collected from WoS. Graph prepared by the authors.

Until 2010, publications indexed in the WoS were relatively scarce. After this period, there was steady growth, culminating in an increase in the number of publications between 2017 and 2018. This growth is consistent with the data presented in Graph 3 on the Evolution of the Number of Scientific Publications in the Database, which analyzed scientific publications in a global context.

The increase observed during the 2017–2018 period may be associated with several factors. One of these factors was likely the hosting of scientific and technological events of significance in Brazil, which highlighted the topic of electric vehicles. An example was the VE Latino Americano 2018, held in São Paulo from September 17 to 19, 2018, where electric vehicles received significant attention from the researchers in attendance (Bland, 2019). Another significant milestone during this period was the Rota 2030 program, introduced in 2018, which provided incentives for research and development in the sector (Brasil, 2020).

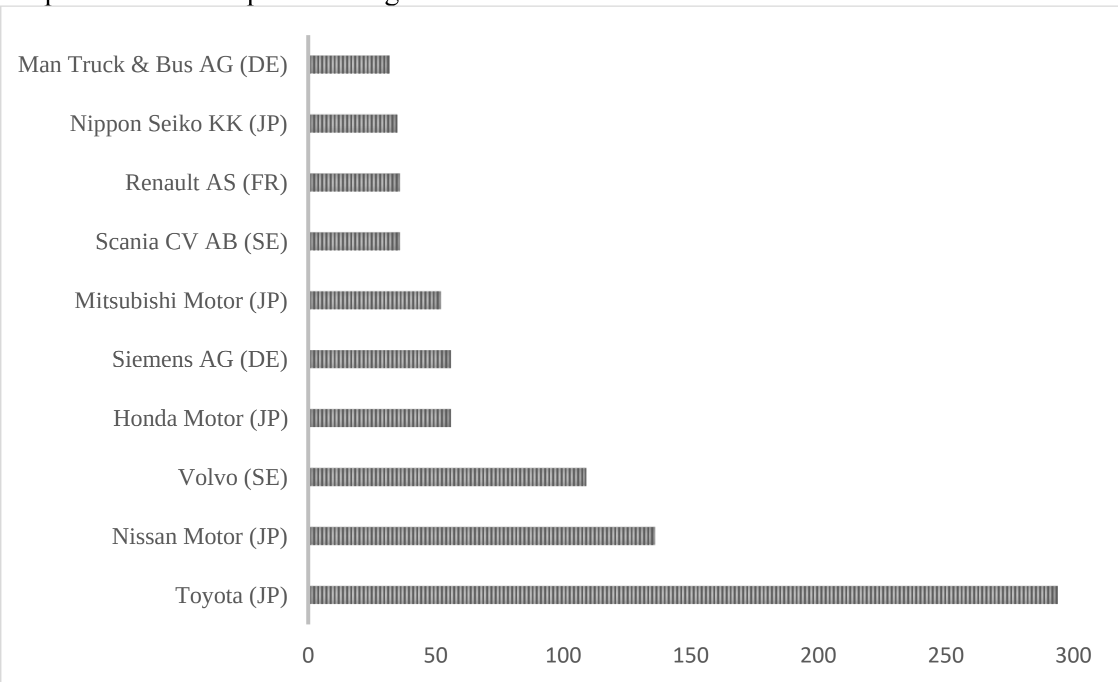
Additionally, during the same period, conferences and scientific events focusing on electric vehicles took place, consolidating them as a relevant and attractive subject of study for the academic community. Another important factor was the growth of the global electric vehicle fleet, which increased by 55% in 2018 compared to the previous year.

Although Brazil still faces challenges related to the low demand for electric vehicles due to insufficient charging points and the high cost of these vehicles in the domestic market, the global landscape shows significant progress. Countries such as China, which leads both in production and academic studies on electric vehicles, have contributed to the increase in global sales. In 2018, China established itself as the country with the largest fleet of electric vehicles in circulation, reinforcing the importance of the topic for researchers and industries (Izo, 2018).

5 Patent Analysis in Electric Vehicles - Technological Innovation Indicators

Patents play a fundamental role as an indicator of technological innovation, reflecting the efforts of companies and researchers in the pursuit of pioneering solutions and technologies. In Brazil, despite the reliance on imported technologies, the electric vehicle sector is beginning to emerge with a growing number of patent registrations, primarily led by multinational companies like Toyota, but also with significant participation from independent inventors. This scenario highlights both the potential and the challenges Brazil faces in advancing the production of its own technology, as discussed by Yamamura et al. (2022). Graph 6 highlights the main companies filing patents in Brazil, revealing the distribution of this innovative effort.

Graph 6 - Main Companies Filing Patents in Brazil



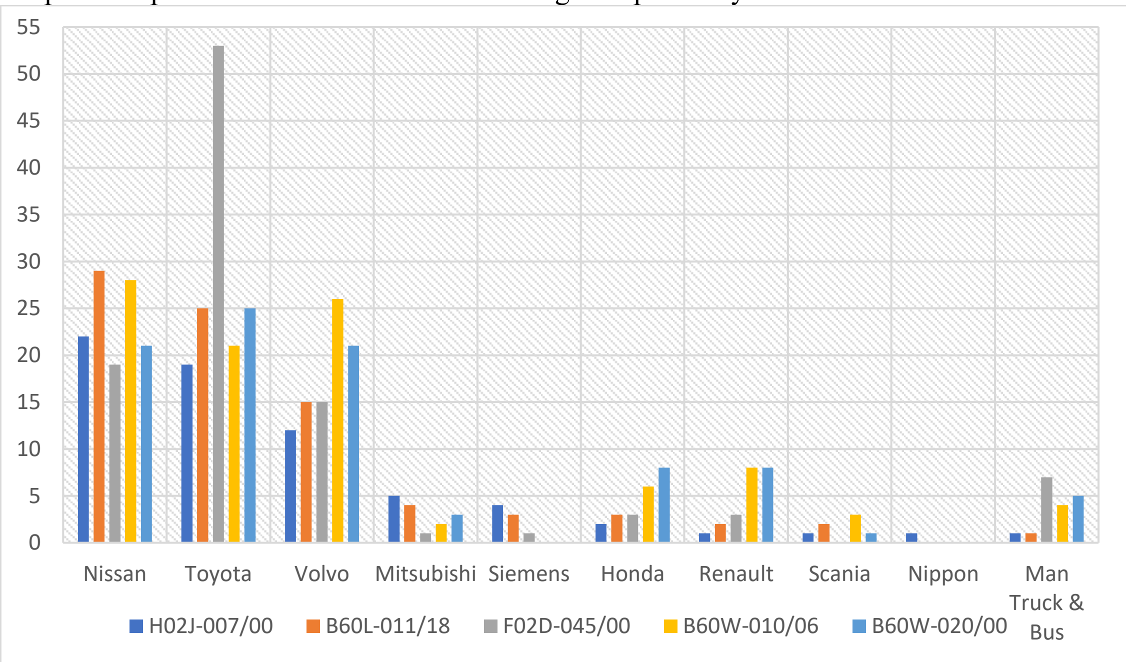
Source: Schiavi (2020). Data collected from the Derwent Innovation Index. Graph prepared by the author.

Based on Graph 6, it is observed that Toyota leads in the number of patent filings related to electric vehicles in Brazil. Following Toyota are Nissan and Volvo, occupying the second and third positions, respectively. Among the top ten companies identified, five are Japanese, two are Swedish, two are German, and one is French, all with established operations in Brazil. These companies operate in various segments of the automotive sector, including vehicle manufacturers, and producers of parts, accessories, and components. Siemens, for example, in addition to its presence in sectors such as energy, infrastructure, and healthcare, plays a significant role in enhancing automotive engines. Meanwhile, MAN Truck & Bus, associated with Volkswagen, with over 75% of its shares controlled by the latter, stands out in the production of heavy vehicles, engines, and other components.

Although many of these companies have facilities in Brazil, some have yet to implement local production systems for electric vehicles, which is considered a crucial element for driving economic development and innovation in the country. To detail the relationship between the companies and the technologies associated with their patents, Graph 7 will present the top ten filers linked to the International Patent Classification (IPC), highlighting the technological areas of greatest interest among these companies.

The information presented so far highlights the leadership of companies such as Toyota, Nissan, and Volvo in patent filings related to electric vehicles in Brazil, as well as the technological diversity promoted by other automotive companies operating in the country. However, to better understand the specific technologies of interest to these companies, it is necessary to explore the data related to the International Patent Classification (IPC). Graph 7 categorizes their patents according to the IPC, enabling the identification of the technological areas that have received the most attention and investment from these companies, thereby highlighting trends and priorities in the development of electric vehicles.

Graph 7 - Top Ten Electric Vehicle Patent-Filing Companies by IPC in Brazil



Source: Schiavi (2020). Data collected from the Derwent Innovation Index. Graph prepared by the authors.

The descriptions of the IPC codes presented in Graph 7 will be detailed further in Table 1, as follows: H02J-007/00, which refers to circuits for charging or depolarizing batteries, or supplying loads from them; B60L-011/18, which addresses the use of propulsion energy derived from batteries or fuel cells, including the combined control of these sources; F02D-045/00, related to electric control in internal combustion engines, particularly functions such as ignition, lubrication, and starting; B60W-010/06, which pertains to the joint control of vehicle subunits, such as combustion engines, in integrated systems; and B60W-020/00, which deals with control systems specifically designed for hybrid vehicles.

According to Assis (2018:68), "[...] these companies have different competitive strategies for innovation," which allows Nissan to maintain a balance in its filings related to electric vehicle technologies. Toyota, despite its dominance across all patent classes presented here, shows a greater focus on patents related to electric controls. It is worth noting that Toyota is the largest automotive company in the market, the leader in global sales, and the top holder of patents related to electric vehicles. Mitsubishi, Siemens, Honda, Renault, and MAN Truck & Bus follow a similar pattern to the companies described above but with fewer patents.

However, Nippon, for example, holds only a single technology related to electric vehicles, focused on vehicle batteries, circuit arrangements for charging or depolarizing batteries, or supplying loads from batteries. Scania, on the other hand, does not have technologies in the area involving electric controls.

Another important point to highlight is that these same companies are the importers of electric cars into the country. According to data provided by ANFAVEA (2020), the main importers include Volvo, BMW, Hyundai, Iveco, Fiat, Ford, Toyota, General Motors, Honda, Mitsubishi, Jaguar, MAN Trucks, Volkswagen, Mercedes-Benz, Nissan, Peugeot Citroën, Renault, Scania, among others.

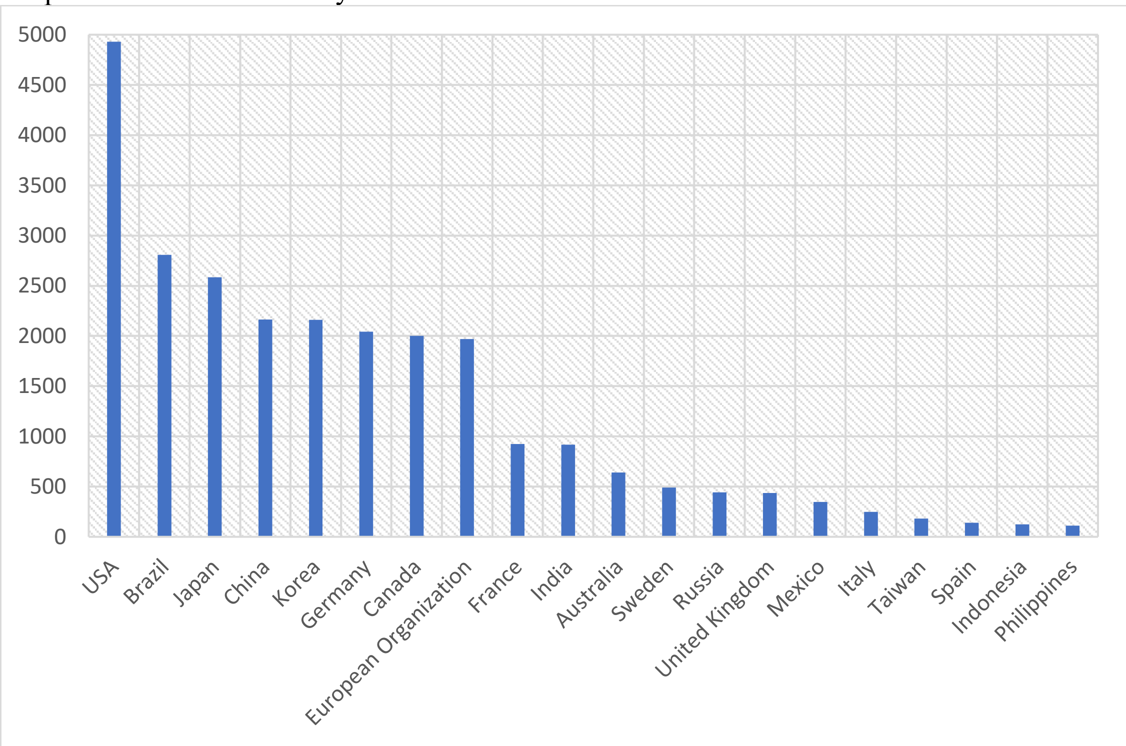
5.1 Overview of Electric Car Patents in Brazil

Technological innovation plays a central role in advancing electric mobility, particularly in the development of electric vehicles (EVs). In this context, patents emerge as an indicator for evaluating a country's scientific and technological progress. In addition to reflecting research and development (R&D) efforts, patent filings reveal which technologies and markets are being prioritized. In Brazil's case, patent analysis helps identify both strategic areas of innovation and the challenges in consolidating its technological sovereignty compared to global leaders such as China, the United States, and Germany.

Considering the relevance of this topic, an analysis was conducted on the documents available in the Derwent Innovation Index (DII) database, which includes a total of 12,965 records related to patents on electric cars. Among these, the data were filtered to identify documents classified as having Brazilian priority, resulting in 3,935 records within the country. This number indicates a moderate participation of Brazil in this context, highlighting the need to invest in public policies and strategies that promote local innovation.

Furthermore, the analysis identified 63 countries with priority patent filings related to electric cars, with the 20 most relevant highlighted in Graph 8. This classification provides an understanding of the global distribution of innovation efforts and Brazil's position within this competitive context.

Graph 8 – Records of Priority Countries for Electric Vehicle Patents in the DII in Brazil



Source: Schiavi (2020). Data collected from the Derwent Innovation Index. Table prepared by the authors.

The analysis of Graph 8 shows that the United States is the leading country in priority patents related to electric vehicles in Brazil, with a total of 4,930 records. This data highlights the central role of the U.S. as a leader in technological innovation in the sector, supported by a robust research and development (R&D) ecosystem and the presence of multinational companies operating globally. Japan, with 2,586 records, ranks third, demonstrating its strength in areas such as electrification and batteries, with companies like Toyota and Nissan playing strategic roles.

Brazil, with 2,880 records, ranks second, highlighting its importance as a developing market and as a recipient of technologies associated with electric vehicles. This number is significant when compared to technological powers like China (2,163 records) and South Korea (2,162 records), yet it still underscores challenges in the production of proprietary technology. Brazil's presence in this context reinforces the need for greater support for local research and innovation, particularly to reduce dependence on imported technologies.

Additionally, countries like Germany (2,043 records) and Canada (2,001 records) demonstrate their relevance, reinforcing global competitiveness and the expansion of their technological industries. The significant number of records from European countries, such as the European Organization (1,969 records), France (925 records), and India (918 records), highlights Europe's leadership in efforts related to sustainability and automotive innovation.

On the other hand, countries like Spain (139 records), the Philippines (112 records), and Indonesia (125 records) have a more limited participation, suggesting that their integration into the global patent market is still in its early stages.

5.2 Technological Mapping

The International Patent Classification (IPC) plays a fundamental role in organizing and retrieving patent-related data, enabling a detailed analysis of technological innovations in the electric vehicle (EV) sector. As highlighted by Schiavi (2016), this classification is essential for structuring patents in an organized manner, facilitating the retrieval of relevant information. In the case of electric cars, the classification encompasses a wide range of technologies, as these vehicles feature components that differ from traditional internal combustion engine technologies. To provide a clearer view of technological innovations, Table 1 presents the five most relevant subclasses of patents related to electric vehicles, with a detailed description of each class, aiding in understanding the dominant technology groups in this sector.

Table 1 - International Patent Classification for Electric Vehicles.

SUBCLASS - DESCRIPTION	MOST UTILIZED IPC CODES
H02J - Circuit arrangements or systems for the supply or distribution of electric power; systems for the storage of electric energy	H02J-007/00 - Circuit arrangements for charging or depolarizing batteries or for supplying loads from batteries
	H02J-007/02 - For charging batteries from the power supply network by converters
B60L - Propulsion of electrically-propelled vehicles; Supply of electric power to auxiliary equipment of electrically-propelled vehicles; Electrodynamic braking systems for vehicles in general; Magnetic suspension or levitation for vehicles; Monitoring of operational variables of electrically-propelled vehicles; Electrical safety devices for electrically-propelled vehicles	B60L-011/18 - Using propulsion energy supplied by batteries or fuel cells; For controlling a combination of batteries and fuel cells
	B60L-003/00 - Electric devices on electrically-propelled vehicles for safety purposes; Monitoring operational variables, such as speed, deceleration, or energy consumption - Methods or circuit arrangements for monitoring or controlling batteries or fuel cells
F02D – Control of Internal Combustion Engines - Accessories for vehicles, acting on a single subunit only, for automatically	F02D-045/00 - Electric control not provided for in groups (electric control of exhaust gas treatment apparatus; electric control of one of

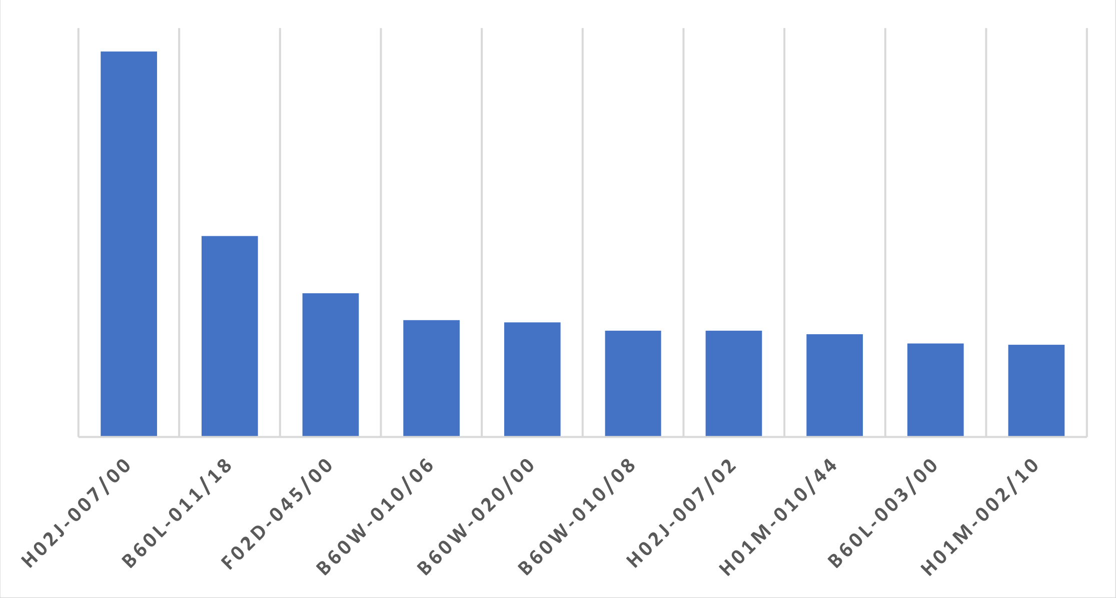
controlling vehicle speed; Joint control of vehicle subunits of different types or functions; Steering control systems for vehicles for purposes other than controlling a single subunit; Cyclically operating valves for internal combustion engines; Lubrication control of internal combustion engines; Cooling of internal combustion engines; Supplying internal combustion engines with fuel mixtures or their constituents; Starting internal combustion engines; Ignition control; Control of gas turbines, jet propulsion, or combustion engines, see the relevant subclasses for these installations.	the functions: ignition, lubrication, cooling, starting, intake heating, see relevant subclasses for these functions)
B60W - Conjoint control of vehicle sub-units of different types or functions; Control systems specially adapted for hybrid vehicles; Control systems for terrestrial vehicles not related to the control of a particular sub-unit	B60W-010/06 - Conjoint control of vehicle sub-units of different types or functions, including the control of internal combustion engines
	B60W-020/00 - Control systems specially adapted for hybrid vehicles
	B60W-010/08 - Conjoint control of vehicle sub-units of different types or functions, including control of electric propulsion units, e.g., motors or generators
H01M – Processes or means, e.g., batteries, for the direct conversion of chemical energy into electrical energy	H01M-010/44 - Secondary cells; Methods of charging or discharging (charging circuits)
	H01M-002/10 - Constructional details or manufacturing processes of inactive parts. Suspension devices; Shock absorbers; Transport or carrying devices; Supports (structural combination of accumulators with charging devices).

Source: (Schiavi, 2020) Adapted from WIPO. Table prepared by the author.

Table 1 shows that subclasses related to electric power supply circuits and systems (H02J), electric vehicle propulsion (B60L), and electric motor control (B60W) are the most frequent in patent filings on electric cars. The H02J subclass, in particular, stands out due to the large number of patents focused on the development of energy storage circuits and devices, such as batteries, a central component of electric vehicles. Meanwhile, the B60L subclass focuses on propulsion systems, with technologies related to the control and efficient use of battery energy. These subclasses highlight the areas of greatest innovation and development in the sector.

Graph 9 presents the distribution of the most commonly used classes within the IPC, providing a clear view of the main technological fields in the development of electric vehicles. This information is crucial for understanding the technological trends dominating the market and the areas with the greatest focus on research and development.

Graph 9 – Most Utilized IPC Groups of Patents for Electric Vehicles



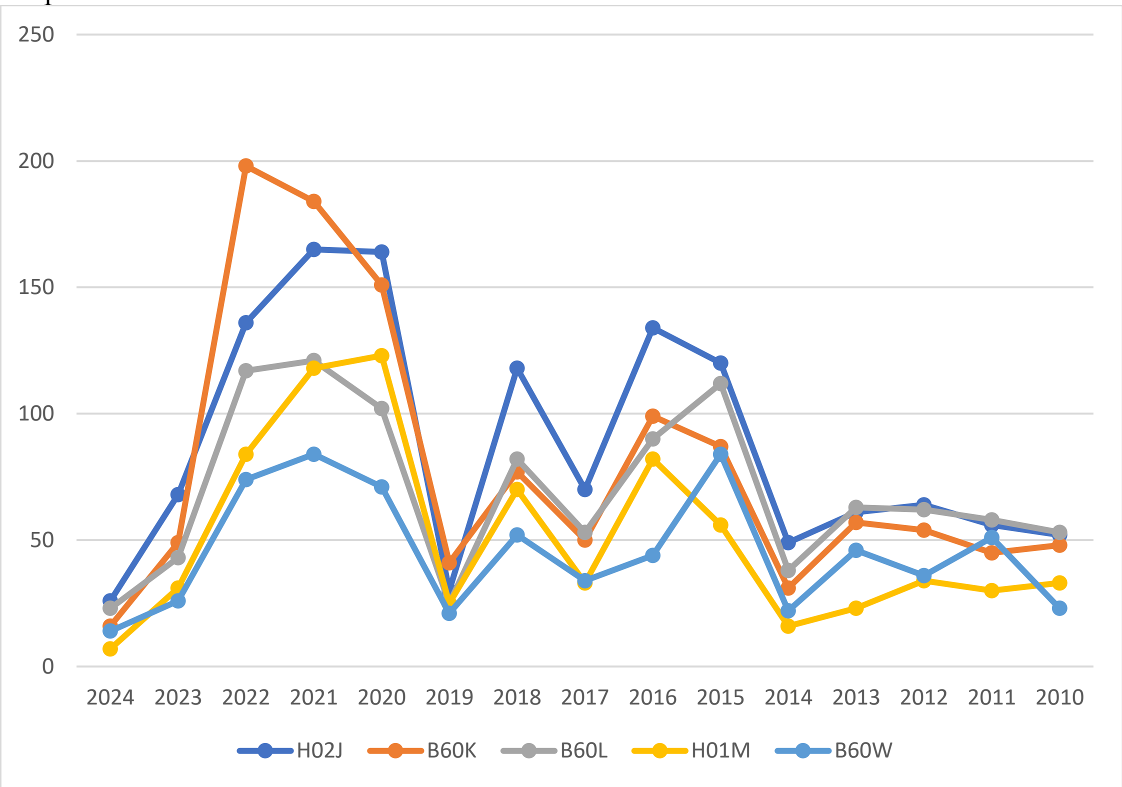
Source: Schiavi (2020). Data collected from the Derwent Innovation Index. Graph prepared by the author.

As highlighted earlier, the two main groups of the International Patent Classification (IPC) related to electric vehicles focus on technologies aimed at control systems, propulsion, and batteries, which are fundamental elements for the development of these vehicle models. These groups are also reflected in the subsequent positions, including the fourth, fifth, and sixth places, which cover complementary technologies.

The remaining classes include innovations such as electric control, lubrication systems, ignition, start-up heating, charging circuits, transport devices, and specific solutions for electrically-propelled vehicles. These technologies are crucial for the functionality, efficiency, and safety of electric vehicles.

Graph 10 illustrates the evolution of these classes over time, providing an accurate view of how technological innovations associated with electric vehicles have progressed. Additionally, it highlights the five subclasses that have shown the greatest growth over the past fourteen years, showcasing trends and priority areas for technological development.

Graph 10 - Evolution of Patent Classes Related to Electric Vehicles Over the Last 10 Years



Source: Data collected from the Derwent Innovation Index. Graph prepared by the authors.

Through the analysis of the IPC codes, it is possible to identify the most relevant technologies for the manufacturing of electric vehicles. It is observed that until 2014, the growth in registrations across the analyzed classes remained relatively balanced. From 2015 onward, three specific codes stood out: H02J - Related to electric vehicle batteries, especially circuit systems for the distribution of electric power. This class is widely utilized for the development of essential technologies for the efficient operation of vehicles; B60L - Focused on electrically-propelled vehicles, this class also pertains to systems that optimize energy consumption and ensure battery performance; and B60K - Addresses the arrangement and assembly of propulsion or transmission units in vehicles, tackling critical technical aspects for the performance and functionality of electric vehicles.

These classes lead technological advancement due to the importance of battery-powered motors, which are fundamental components in electric vehicles. Since the market began investing more in this segment, the automotive industry has promoted significant innovations to overcome past limitations, such as inferior performance compared to combustion vehicles.

Additionally, other classes, such as H02K (dynamic electric machines), B62D (vehicle bodies and chassis), F02D (combustion engine control), B60T (braking systems), H02P (electric motor control), H02M (power conversion circuits), H01M (batteries), G06F (control and computing systems), B60W (integrated vehicle control), and F16H (transmissions), also show consistent growth, consolidating their relevance in the technological landscape. However, the H01R class, which deals with electrical connections, exhibited slower growth compared to the others, indicating a lower rate of innovation in this segment.

Finally, it is important to note that the data for 2023 and 2024 may be incomplete due to the two-year confidentiality period associated with patents and potential delays in database updates. This context underscores the need for continuous analyses to fully understand the impact of technological innovations in the electric vehicle sector.

5.3 Challenges for Brazil in Developing the Electric Vehicle Sector

Despite Brazil's significant energy potential due to its renewable-based energy matrix, the country still faces substantial challenges in advancing the electric vehicle sector. The lack of integrated public policies and strategic partnerships between academia, industry, and government hampers the progress of the technological innovations needed to consolidate this industry.

According to data from ANFAVEA (2020), the main companies importing electric vehicles into Brazil include brands such as Volvo, BMW, Hyundai, Fiat, Ford, Toyota, General Motors, Honda, Mitsubishi, and Volkswagen, among others. Additionally, some Brazilian and foreign universities have also stood out in registering patents related to the development of technologies for electric vehicles, particularly essential parts and components, as shown in Table 2.

Table 2 - Universities Holding Patents on Electric Vehicles in Brazil.

UNIVERSIDADES	Nº REGISTROS
UFSM - Univ. Federal de Santa Maria	6
UNICAMP - Univ. Estadual de Campinas	5
UFRGS - Univ. Federal do Rio Grande do Sul	5
UEL - Univ. Estadual de Londrina	4
UC - Univ. Califórnia	3
UFPB - Univ. Federal da Paraíba	3
UTFPR - Univ. Tecnológica Federal do Paraná	3
FUCS - Fundação Univ. Caxias do Sul	3
UFPR - Univ. Federal do Paraná	2
UFMG - Univ. Federal de Minas Gerais	2
UFSC - Univ. Federal de Santa Catarina	2
UDESC - Fundação Univ. do Estado de Santa Catarina	2
Univ. Friedrich-Schiller de Jena	2
Univ. Bristol	1
UEM - Univ. Estadual de Maringá	1
UFC - Univ. Federal do Ceará	1
UFFS - Univ. Federal da Fronteira do Sul	1
UFPE - Univ. Federal de Pernambuco	1
UFRJ - Univ. Federal do Rio de Janeiro	1
UFSJ - Univ. Federal São João Del-Rei	1
Univ. Katholieke Leuven	1
UC3M - Univ. Carlos III de Madrid	1
UEMA - Univ. Estadual do Maranhão	1
USP - Univ. São Paulo	1
Univ. Sydney	1

Source: Schiavi (2020). Data collected from the Derwent Innovation Index. Graph prepared by the author.

The universities that registered patents in Brazil are led by the Federal University of Santa Maria (UFSM), with six registrations, followed by UNICAMP and the Federal University of Rio Grande do Sul (UFRGS), both with five. These registrations represent only 2.55% of the total number of patents registered in the country, indicating that the role of universities, although important, remains limited in absolute numbers.

Examples of patents registered by universities highlight their contribution to the technological advancement of the sector. For instance, UDESC registered a multifunctional energy conversion system for battery charging, suitable for electric vehicles with alternating current input ports. UFSM developed a multilayer inverter with a main direct current port connected between terminals. Meanwhile, UNICAMP filed a patent for a fuel tank waste collector, contributing to the technological chain of hybrid or electric vehicles.

These innovations highlight the importance of collaborations between companies and universities. Strategic partnerships can further drive the development and practical application of technologies associated with electric vehicles. Figure 1 presents a collaboration network between the ten leading companies and universities that registered patents in Brazil, showcasing how these interactions can create value for the automotive and technological sectors.

However, the lack of a coordinated approach and incentives to foster such partnerships undermines Brazil's potential to compete in the electric vehicle market. Promoting public policies that integrate universities, industry, and the government is crucial to overcoming these barriers and positioning the country as a significant player in this strategic sector.

Figure 1 - Collaboration Network Between Leading Companies and Universities

Source: Schiavi (2020). Data collected from the Derwent Innovation Index - Figure prepared by the author.

The analysis of partnerships for the development of technologies related to electric vehicles reveals two main patterns. In the business sector, it is observed that some companies establish significant strategic collaborations. An example is the partnership between Nissan and Renault, which has existed since 1999 and resulted in 18 joint patents focused on the development of electric vehicles (Nissan, 2024). This alliance combines production operations and commercial strategies between the French and Japanese companies. Another notable example is the partnership between Volvo and Renault, which led to the creation of the Renault Trucks brand, one of the largest truck manufacturers in Europe, while Volvo also maintains collaborations with MAN Trucks, specializing in high-power trucks and engines, strengthening innovation in the heavy transport sector (Volvo Trucks, 2024).

However, it is notable that many companies choose to protect their innovations independently, seeking competitive advantages in the market. This approach limits the number of broad partnerships and may constrain the acceleration of innovation in the automotive sector.

On the other hand, in academia, only two notable partnerships between Brazilian universities were identified: the Federal University of Santa Maria (UFSM) and the Federal University of the Southern Border (UFFS), both located in the state of Rio Grande do Sul. These collaborations, although limited, represent important contributions to the development of technologies related to electric vehicles.

Data from the Derwent Innovation Index indicate the absence of partnerships between companies and universities in Brazil, despite the significant role of academic institutions in scientific production and knowledge expansion on the subject. This scenario highlights an opportunity for future progress, with the potential to foster partnerships that drive innovation and the development of urban infrastructure necessary for electric mobility.

6 Incentives for Charging Infrastructure and Diversification of Energy Sources

The Brazilian automotive industry, although playing a significant role in producing parts for electric vehicles, has not yet consolidated the assembly of these vehicles in the country. Most of the parts produced in Brazil are exported to international manufacturers, highlighting a gap in the local development of this technology.

A promising initiative was introduced by Companhia Paulista de Força e Luz (CPFL), which launched a pilot project for the technical and commercial integration of electricity into corporate fleets of electric vehicles. According to CPFL (2024), the project aims to create a real-world electric mobility laboratory in the metropolitan region of Campinas, assessing the impacts of this technology on the electrical system, including energy demand and necessary adjustments to distribution infrastructure. These initial studies have the potential to support the expansion of actions to other regions, provided they yield positive results. However, several structural and strategic issues hinder the widespread adoption of electric vehicles in Brazil. Among these, the following stand out:

- Why does Brazil, with its technical capacity, choose to import electric cars instead of producing them locally?
- What are the comparative benefits between electric vehicles and flex-fuel technologies?
- Does the country gain or lose by prioritizing its diversified energy matrix and continuing to invest in flex-fuel technology instead of keeping up with the global advancement of electric vehicles?

Brazil holds a unique position on the global stage. Despite being one of the largest oil producers, its energy matrix is primarily composed of renewable sources such as hydropower, charcoal, and biomass (EPE, 2024). This distinction places the country in a strategic position to explore electric vehicles powered by clean sources, reducing carbon emissions and reinforcing its commitment to sustainability goals.

However, progress in this segment requires targeted incentives, both for the expansion of charging infrastructure and for the diversification and integration of energy sources. Studies such as Rocha (2018) highlight that the lack of EV charging infrastructure is one of the main obstacles to the expansion of this market in Brazil. Additionally, public-private partnerships and subsidies could be crucial to attracting investments and developing competitive local technologies.

6.1 Brazilian Energy Matrix

This configuration of Brazil's energy matrix results from an economic development process that began in the 20th century and intensified from the 1970s onward. During this period, Brazil faced significant challenges, such as low primary energy consumption, increasing urbanization, and rapid population growth, which demanded strategic responses to align energy development with industrial and population needs. According to Tolmasquim, Guerreiro & Gorini (2007:49), this phase was characterized by: "[...] an expressive industrialization process, with the establishment of energy-intensive plants, and a notable demographic expansion, accompanied by a rapid increase in the urbanization rate [...]".

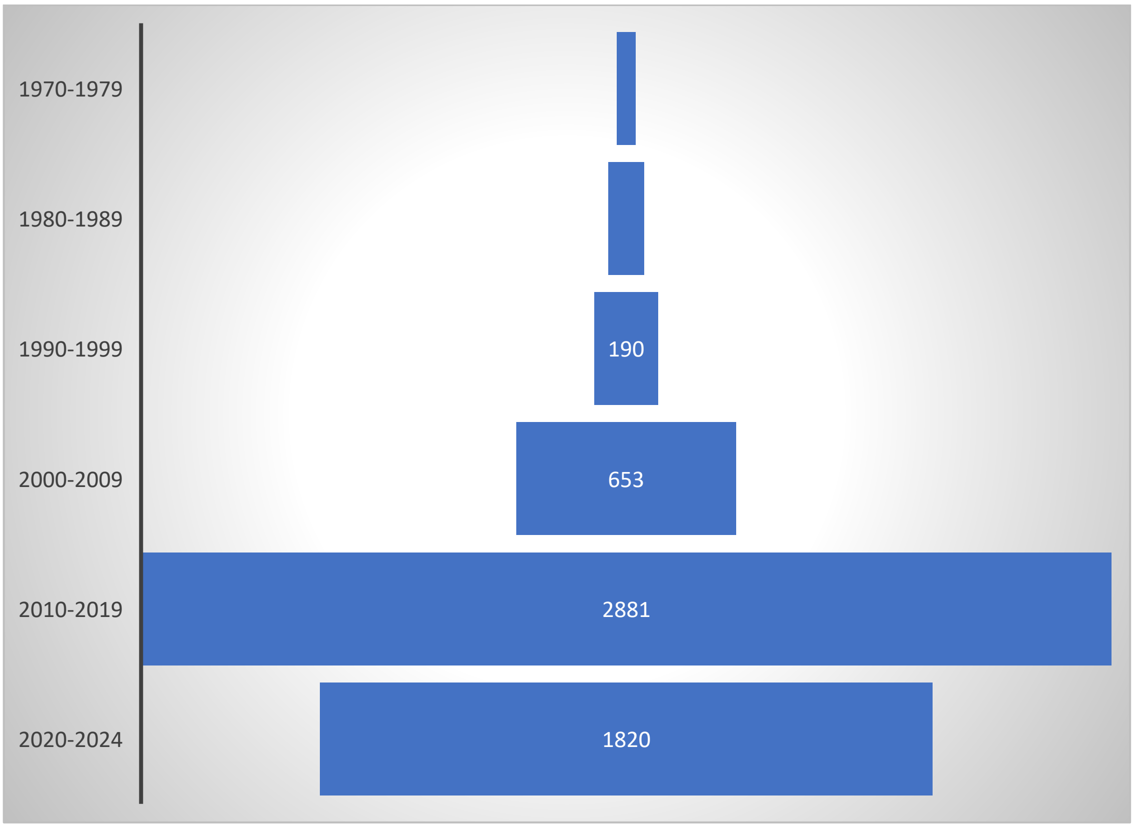
Since then, Brazil has adopted policies to diversify and strengthen its energy matrix, prioritizing renewable sources such as hydropower, biomass, and wind. According to a recent report by the Energy Research Company (EPE, 2024), Brazil stands out globally for its low dependence on fossil fuels, with over 45% of its energy matrix composed of renewable sources, compared to the global average of around 15%.

This consolidated model reflects the impact of structured policies, such as the National Alcohol Program (Proálcool) in the 1970s and recent incentives for solar and wind energy, which have contributed to reducing carbon emissions and strengthening the country's energy security (Brasil, 2024).

With the growing energy demand associated with the electrification of vehicle fleets, Brazil faces new challenges in expanding its generation capacity and electrical infrastructure. In this context, diversifying the energy matrix remains essential to meet the increased demand without compromising environmental sustainability and economic stability.

Graph 11 reflects the gradual growth of technology related to electric vehicles, aligned with the development of infrastructure and the diversification of energy sources. From 1970 to 2024, a consistent increase in registrations is observed, especially after 2014, indicating the advancement of technological innovations in the automotive sector. This progress is linked to investments in charging infrastructure and public policies that support the transition to electric mobility, highlighting the importance of stronger alliances between industry, government, and universities to accelerate this transformation.

Gráfico 11 - Progresso dos documentos de patentes no Brasil sobre o veículo elétrico no decorrer dos anos



Source: Schiavi (2020). Prepared by the author.

Graph 11 presents the progress of patent filings in Brazil on electric cars from 1950 to 2024, highlighting a significant upward trend during the period from 2000 to 2024. Although the graph shows the increase in patent registrations over the years, it is important to note that Brazil has become a strategic location for patent filings by international companies. Many of these filings are not made by Brazilian companies but by global corporations that recognize Brazil as a promising market. This reflects the growing interest in the transition to electric mobility, especially due to environmental concerns such as CO2 emissions and their contributions to climate change. The increase in the number of patents and scientific production from the 2000s onwards is a reflection of these global issues. Moreover, the disparity between patent filings and scientific production (about 16%) reveals a greater focus on technological development compared to scientific research in Brazil, a trend that has intensified since 2010. The period of 2017 and 2018 was particularly notable, with peaks in filings, indicating a strong movement of innovation and preparation for the energy transition. The mobilization of international companies and the increasing demand for more sustainable alternatives reinforce Brazil's potential to lead the electric vehicle industry, especially with its abundant renewable energy sources.

6.2 Electric Vehicles in Brazil

Brazil has the potential to accelerate its transition to electric mobility and fleet electrification, and much to learn from countries that are ahead in this vehicle transformation, such as China and the United States. The adoption of public policies aimed at expanding infrastructure and providing incentives for electric mobility, following the successful models of global leaders, could speed up the process in the country, aligning with the technological and environmental advances already underway in the international landscape.

To contextualize the need for stronger and more impactful policies, it is also important to observe the landscape of scientific publications and innovations related to electric mobility.

Graph 2, for example, provides an analysis of the number of publications per year made by different countries, highlighting those that have contributed the most to the advancement of electric vehicle technology. This analysis not only demonstrates the evolution of scientific interest in the topic but also points to the countries that are gaining prominence in terms of knowledge production and the development of new solutions.

In this regard, the comparison between countries offers valuable insight for Brazil to understand its current position, how it aligns with these trends, and how it can accelerate its own journey toward a more sustainable and technologically advanced future. The focus now shifts to how Brazil can incorporate these strategies to shape its public policies more effectively, favoring the adoption of electric mobility technologies in the country.

7 Conclusion

This study explored the evolution of electric mobility in Brazil, focusing on how public policies can drive fleet electrification and transform the automotive sector. The research problem, centered on the impact of fleet electrification in Brazil and the challenges for the national electrical system, revealed the importance of aligning with global trends, particularly by learning from leading countries like China, which have implemented effective policies for sustainable development and transportation electrification.

The analysis of patents and scientific publications over the past decades demonstrates that, although Brazil is moving toward electric mobility, it still faces significant challenges. The growing scientific production, along with the increase in the number of patents filed in the country, reflects an innovation environment but also highlights that Brazil relies on international companies to drive this technology. This underscores the urgent need to develop national public policies that promote local research and development.

The article also addressed the importance of encouraging the necessary infrastructure, improving scientific production, and strengthening Brazilian patents. By focusing on examples from China and the United States, Brazil can structure a more effective regulatory and incentive environment, ensuring that the transition to an electric fleet is not only feasible but also sustainable in the long term. In this way, the study contributes to the reflection on how Brazilian public policies can support electric mobility, leveraging global lessons for a more sustainable and efficient future.

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