ISBN: 978-628-95207-8-1. ISSN: 2414-6390. Digital Object Identifier: 10.18687/LACCEI2024.1.1.1312

# Bibliometric Analysis of the Use of Electric Vehicles as a Carbon Footprint Reduction Alternative

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***Abstract*– Currently, the main source of greenhouse gas (GHG) emissions comes from the burning of fossil fuels. The European Parliament states that the transport sector, especially automobiles, is responsible for 60% of CO2 emissions. To reduce this high percentage, measures are being implemented to reduce the carbon footprint using green technologies such as electric vehicles. The objective of the research was to evaluate through a bibliometric analysis the use of electric vehicles as an alternative to reduce the carbon footprint. The study worked with research published in the Scopus, Web of Science, Science Direct and Proquest databases from January 2010 to September 2021. The results showed that 1017 researches touched the topic of electric vehicles and their effect on carbon footprint reduction, being the year 2021 with the highest number of publications. The journal with the highest number of publications was "Energies" from the Scopus, Web of Science and Proquest databases. The country with the most research on the topic under study is the USA with 306 documents. The most researched type of vehicle is the pure electric vehicle for being an efficient alternative in reducing the carbon footprint, reducing emissions by an average of 91%, depending on the number of kilometers traveled and the storage capacity of the battery.***

***Keywords*-- electric vehicles, carbon footprint, bibliometric analysis, CO2 emissions.***

## I. Introduction

The main source of emissions that contribute to the carbon footprint comes mostly from the incineration of fossil fuels. The excessive use of these fuels has generated negative impacts on the environment such as droughts, floods, storms and earthquakes, and the way to reduce these consequences is to take actions mainly in the transportation sector, since its contribution to these emissions is significant. Light vehicles consume the most energy, using diesel and gasoline for their operation, thus generating a large percentage of emissions [1].

Currently, environmental footprint assessment has been done mostly considering 3 fronts. These bbs effect on the environment can be generated both directly and indirectly, as well as the extent to which natural resources are used and the emissions generated as a result of a product or activity. These 3 measures help to understand the effect of the carbon footprint; however, recent studies have included within the analysis the impact on water and land through the use of biofuels by evaluating the effect on the environmental footprints produced by traditional vehicles, all this using as a measure the units of distance traveled [2].

In the production and use of a product there is an impact on the environment, which could be linked to greenhouse gases (GHG), which are the main cause of global warming. These gases are emitted at various stages in the production of a product and are directed into the atmosphere. With the need to control these emissions, the carbon footprint has emerged [3]. The carbon footprint is a tool that shows the index of GHG emissions, which quantifies the gases expelled directly and indirectly into the atmosphere by a given process. This tool is highlighted for its simplicity and direct relationship with the Kyoto Protocol, as well as for its usefulness in environmental policy and decision making [4].

Traditional combustion vehicles are considered one of the major contributors of carbon dioxide (CO2) emissions, which directly contribute to the increase of the carbon footprint. This is refuted by the report issued by the European Parliament which indicates that 60.7% of CO2 emissions come from vehicles classified as automobiles [5]. This industry is highly polluting, experiencing a progressive exponential increase of 5% annually, surpassing 900 million vehicles in 2013 and it is projected that the fleet will increase to 1700 million vehicles by 2035, considering that approximately 20 million barrels of oil are consumed per day, this results in an industry that contributes substantially to CO2 emissions [6]. The transportation sector is the generator of 25% of global CO2 emissions, and vehicle use is responsible for 74% of the sector's total emissions [7].

Carbon dioxide (CO2) is largely produced by the industrial, civil and transport sectors, the latter being a generator of 23 gigatons of carbon dioxide (GtCO2) [8]. In Italy, since 1990 energy consumption has increased considerably by 14.3%, and in 2016 they consumed 39.1 million tons of oil equivalent (Mtoe), representing 33.7% of the final energy use in the entire automotive sector [9]. These figures with alarming results have triggered concern on the part of governments around the world, indicating that immediate actions should be established with the aim of reducing the consequences of GHG and consequently the impact on climate change.

To reduce these emissions, the automotive sector and technological advances have led to the introduction to the market of a new type of electric vehicle (EV) such as plug-in electric vehicles (PEV) that have an emerging charge and add to the benefits of an EV, using a fuel cell or battery as a power source [10]. According to the International Energy Agency

**Digital Object Identifier:** (only for full papers, inserted by LACCEI).
**ISSN, ISBN:** (to be inserted by LACCEI).
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(IEA), a growth in the electric vehicle market of 3 million was recorded in 2017 and reached over 5 million in 2018 among Asian, North American and European markets [11]. That is due to the policies issued by governments where they promote the acquisition of electric vehicles over fossil combustion vehicles [12]. As a result of the policies implemented worldwide, countries such as Norway achieved a market share of 46% for electric vehicles, Iceland 17% and Sweden 8%, all of them referents in innovation and commitment to the environment [11].

An electric vehicle (EV) is defined as a transportation vehicle that is propelled by one or more motors powered by electric energy or traction energy; these vehicles generate multiple economic and environmental benefits [10]. In recent years, brands such as Mitsubishi, Nissan, Renault, Ford and the transnational General Motors have started with the mass production of electric vehicles, this because it was evidenced that the advantages offered go beyond the economic field, where vehicles no longer have exhaust pipe and also show efficiency in its powertrain, reduction to urban air pollution [13]. Electric vehicles bring benefits both in the environmental field (radically improving air quality) and reducing noise pollution, and by not having a gearbox, they have a better response in acceleration and braking efficiency compared to conventional vehicles that due to the heat dissipated by constant braking, sooner or later suffer from a loss in vehicle performance [14]. Likewise, since there is an improvement in environmental conditions with the use of these vehicles, there is a direct and positive impact on the welfare of the population since they do not produce CO2 [15]. One of the main challenges for manufacturers is to improve the efficiency of the batteries used for these vehicles, since currently they have not been able to store enough energy, reaching a range of 250 km per recharge; however, the new models offer a range of up to 400 km in their new versions [16]. Likewise, indirect emissions from electricity production can become significant depending on the volumes of energy required to power the vehicle fleet [12].

Considering the problematic reality detailed in previous paragraphs, the present research aimed to evaluate through a bibliometric analysis the use of electric vehicles as an alternative to reduce the carbon footprint. Bibliometric analysis is a methodology used to analyze the quality and quantity of research on a topic determined by applying mathematical methods [17]. In this analysis, various indicators such as academic publications, scientific journals, scientific institutions, authors and countries cited are applied, and researchers can evaluate participation in academic research, as well as provide a transparent, static and systematic representation of research [18]. To achieve this objective, the following were considered: to determine the number of researches that dealt with the use of electric vehicles as a carbon footprint reduction alternative; to identify the scientific journals with the highest production of articles regarding the efficiency of using electric vehicles as a carbon footprint reduction alternative; to identify the country with the highest number of publications regarding the use of electric vehicles as a carbon footprint reduction alternative; to identify the existing types of electric vehicles and to determine the impact of using electric vehicles on carbon footprint reduction; and to determine the impact of using electric vehicles on carbon footprint reduction.

## II. Methodology

### A. *Type of study*

The current research was elaborated under a quantitative approach and was of an applied and retrospective type given that studies prior to the research are used; in addition, the research had a non-experimental design because its execution was carried out without the manipulation of variables. On the other hand, it is descriptive and explanatory because it specifies and explains the elements or aspects of the object of study.

### B. *Sources of information and search strategy*

Specialized databases such as Scopus, Web of Science, Science Direct and Proquest were used in this research. For the search of information, different keywords were established such as electric vehicle, plug-in hybrid, hybrid electric, carbon, carbon dioxide, carbon footprint and climate change. These keywords were found in the abstracts, titles and keywords of the various articles and reviews. Boolean operators such as AND and OR were also applied, widening the search area and reducing erroneous results related to the research topic. The period that includes the selected research is from January 2010 to September 2021, where documents that include keywords according to the topic under study were considered.

### C. *Inclusion and exclusion criteria*

For the execution of this bibliometric analysis work, studies with information on electric vehicles, carbon dioxide reduction and carbon footprint reduction were taken into consideration. All this, with the purpose of delimiting the work, and only published works were included that were at most twelve years old, areas of interest according to the line of research, key words, language and country of origin. In addition, documents such as scientific articles and reviews mentioning the different types of electric vehicles were included.

### D. *Data extraction and processing*

The data from the database were downloaded in CSV, plain text and RIS format, used to obtain the graphs for interpretation. VOSviewer software (version 1.6.16) was used to process the data; this software allowed the construction and visualization of the bibliometric networks of the articles and reviews.

## III. Results and Discussion

### A. *Analysis of the intersection of articles in databases*

The number of documents published in the Scopus, Web of Science, Science Direct and Proquest databases in the

period from January 2010 to August 2021 are represented in Figure 1, showing that the Scopus database shows a greater number of documents referring to the subject of study.

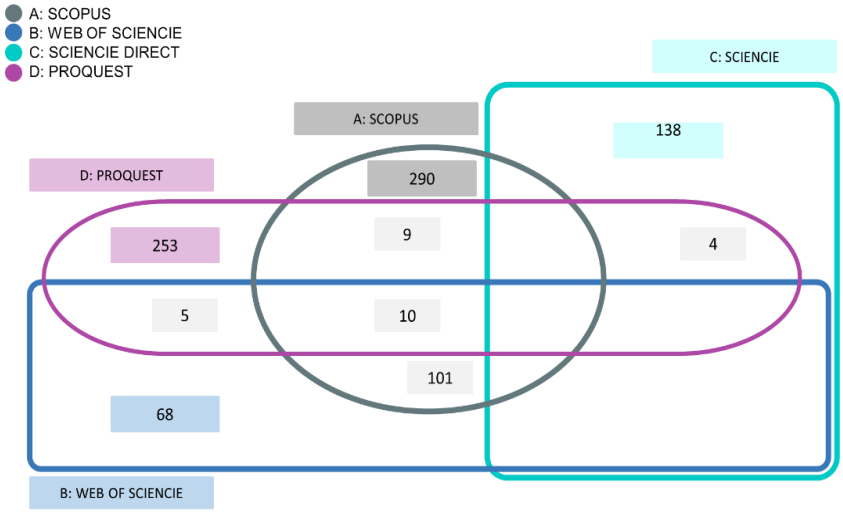


Fig. 1 Intersection of documents downloaded from databases

*B. Trends in database publications*

Considering the publications in the databases, since 2010 there has been an average growth of 8.33% over the previous year (see Figure 2). The last three years have accounted for 46.3% of the publications, and it is expected that by 2022 between 50 and 95 research papers will be published per database.

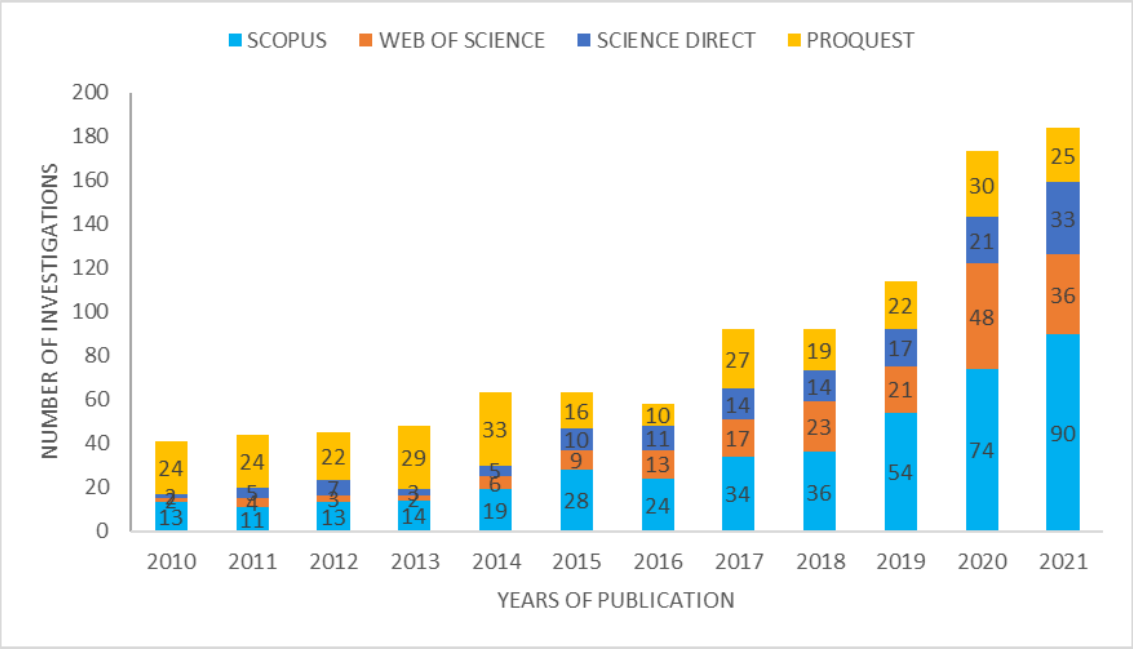


Fig. 2 Trend of documents published per year in databases

*C. Main journals with the highest number of publications in the databases*

The journals with the highest scientific production are "Energies" with 29% of published documents, "Environmental science and technology" with 22% of documents and "Journal of Cleaner Production" with 21% of publications. Other authors such as Ref. [19] determined that the journals with the highest amount of scientific production are "Journal of Power Sources", "International Journal of Hydrogen Energy" and

"International Journal of Crashworthiness" with more publications in the field of study. Also, Ref. [20] found that "Journal of Power Source" is the journal with the largest number of publications compared to other journals.

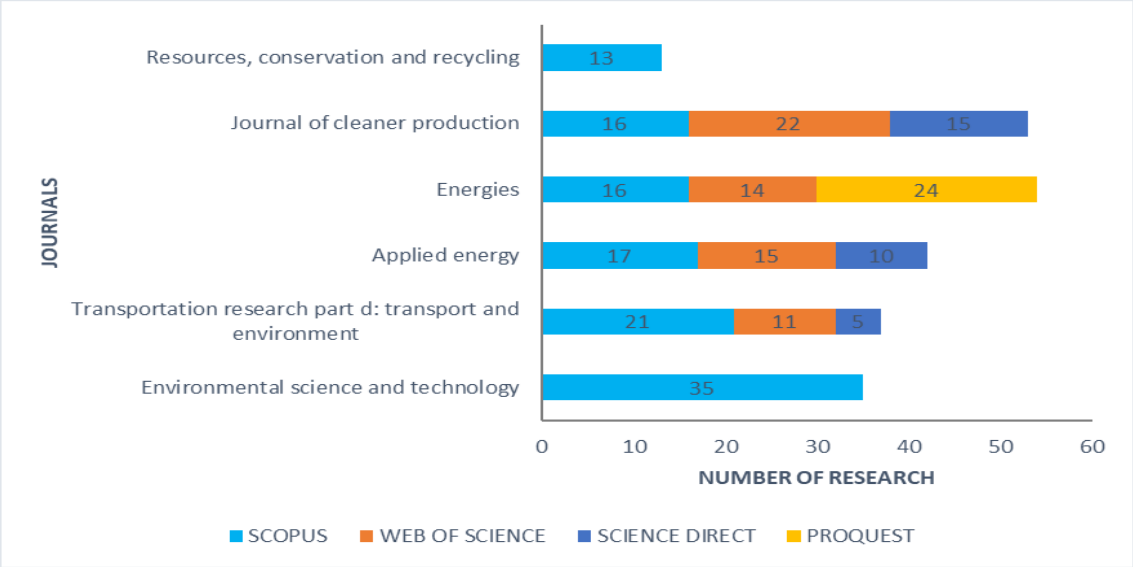


Fig. 3 Journals with the most publications in the databases

*D. Analysis of the countries with the highest number of scientific research in the databases*

The countries with the highest scientific production published in the databases are the USA with an average of 30% of published documents, followed by the United Kingdom with 13% of publications and China with 10% of published documents on the topic of study (see Figure 4). Likewise, Ref. [21] stated that the USA contains 26.75% publications obtaining the highest rate of research, followed by China and the UK. Also, Ref. [22] stated that in recent years, China has increased its research on transportation while the U.S. has focused on intelligent transportation system. Other authors such as Ref. [23] stated that China is the leading country in research in the energy sector, renewable energies and the use of electric vehicles. On the other hand, in the USA, European Union and Australia there are relatively few cases of research on the subject of study. The author's statement differs since it has been determined that the U.S. is the country with the largest number of research publications in the field of transportation.

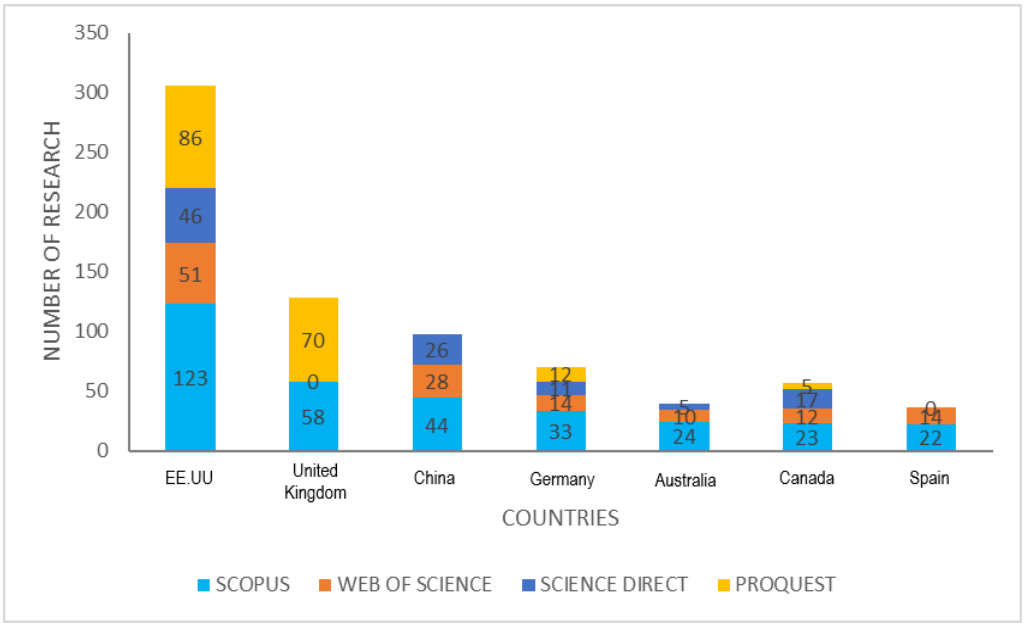


Fig. 4 Countries with the highest number of publications in the databases

*E. Analysis of the most cited authors in the databases*

In the Scopus database, the most cited authors were Wallington and Elgowainy. In the Web of Science database, the most cited authors were Sovacool and Lance. In ScienceDirect, the most representative authors are Ekins, Evagelisti and Lettieri. However, in the Proquest database, the 25 authors represented in the bibliometric network have the same co-citation in the research papers (see Figure 5, Figure 6, Figure 7 and Figure 8).

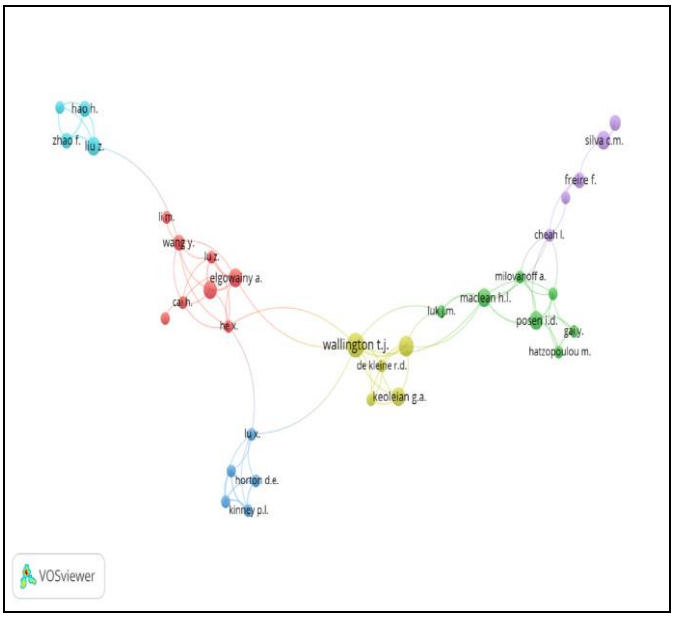


Fig. 5 Bibliometric network of the most cited authors between the years 2010-2021 in the Scopus

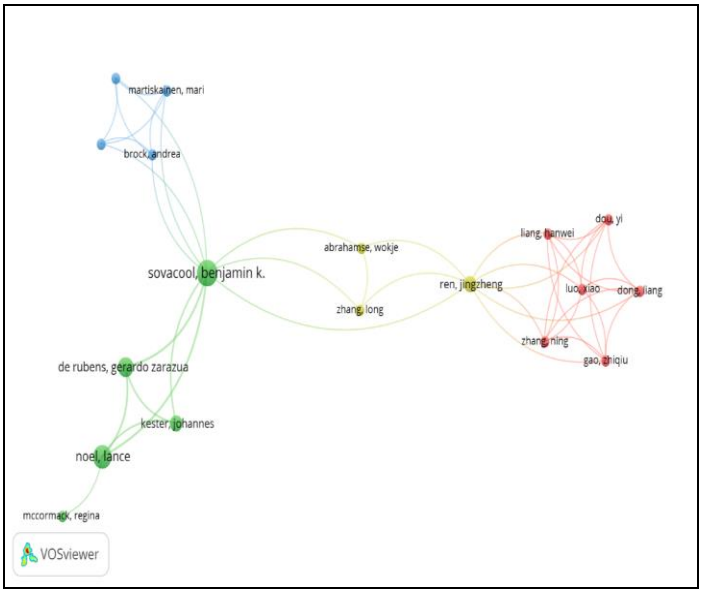


Fig. 6 Bibliometric network of the most cited authors between the years 2010-2021 in Web of Science

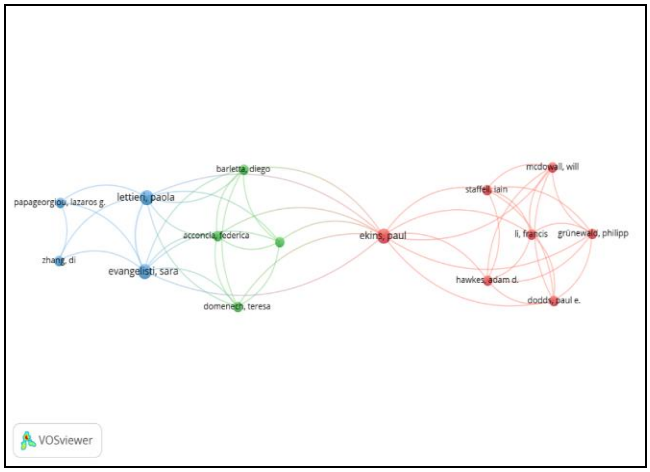


Fig. 7 Bibliometric network of the most cited authors between the years 2010-2021 in Science Direct

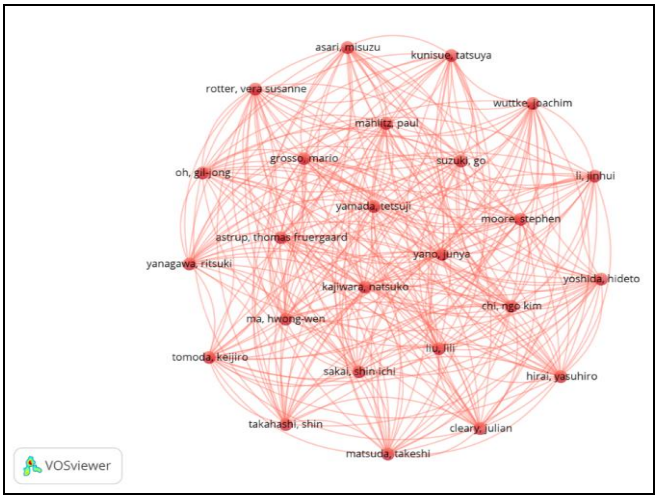


Fig. 8 Bibliometric network of the most cited authors between the years 2010-2021 in Proquest

*F. Analysis of the most cited keywords in the databases*

In the Scopus database, the most repeated keywords are "electric vehicles", followed by "climate change" and "carbon footprint" with 130, 42 and 33 occurrences, respectively. Likewise, in the Web of Science database, the most repeated keywords are "electric vehicles", "carbon footprint" and "climate change" with 68, 23 and 21 occurrences, respectively. In ScienceDirect, the most repeated keywords are "electric vehicles", "life cycle assessment" and "renewable energy" with 32, 15 and 12, respectively. For Proquest, the most occurring keywords are "technology", "electric vehicles" and "energy springs" with 84, 78 and 44 occurrences, respectively (see Figure 9, Figure 10, Figure 11 and Figure 12).

For Ref [24], the influence of the keywords controls the volume of the circle and the label, while the connecting line between the keywords is revealed as a conjunctive connection. Different colors are used to describe different groups depending on the area of expertise. Likewise, the trend

regarding the keywords with the highest occurrence are "electric vehicles", "climate change", "carbon footprint", "life cycle assessment", "technology", "energy resources and "renewable energy", these words are related to the topic of study and are found in the different databases. Ref [25] determined that the main keywords with the highest occurrences were "electric vehicles", "renewable energy", "microgrids", "smart grids" and "energy efficiency", indicating as a result that the future of sustainability is high efficiency and exploration of new renewable resources.

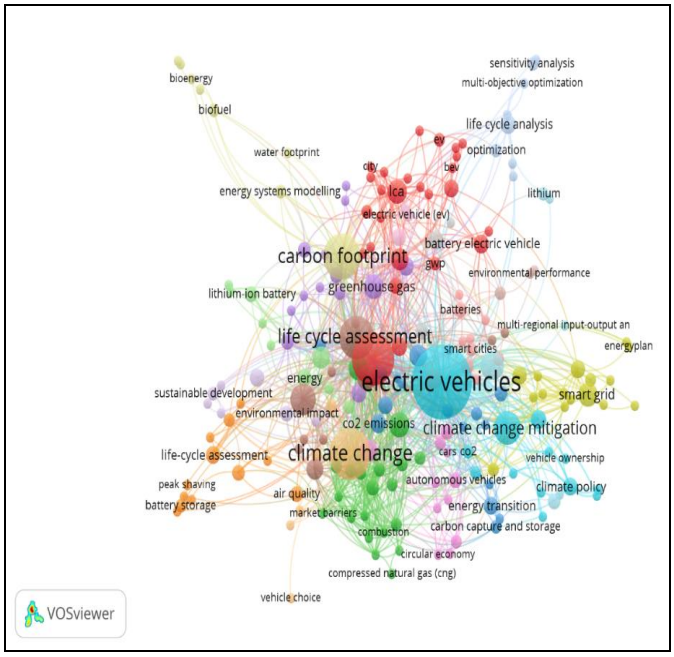


Fig. 9 Bibliometric network of the most cited keyword in Scopus

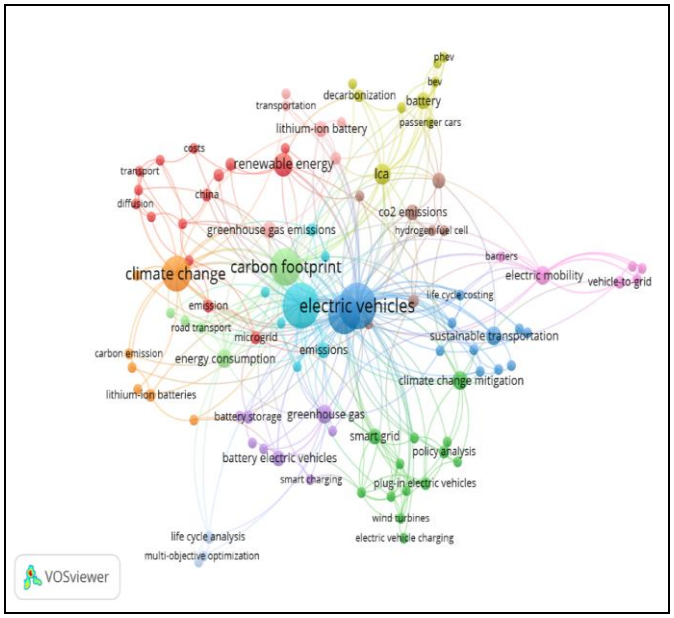


Fig. 10 Bibliometric network map of the most cited keywords in Web of Science

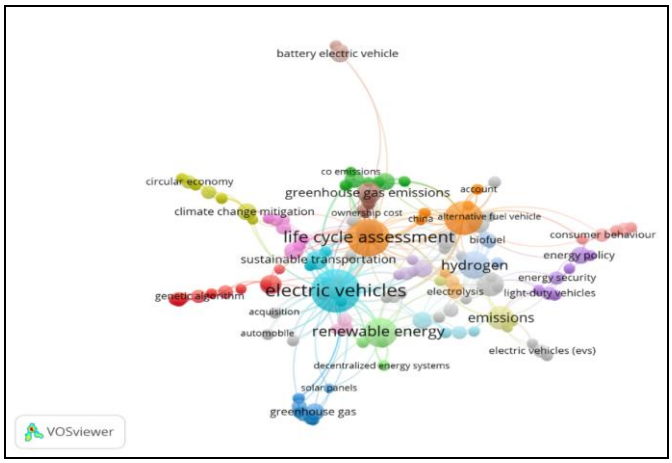


Fig. 11 Bibliometric map of the most cited keyword in Science Direct

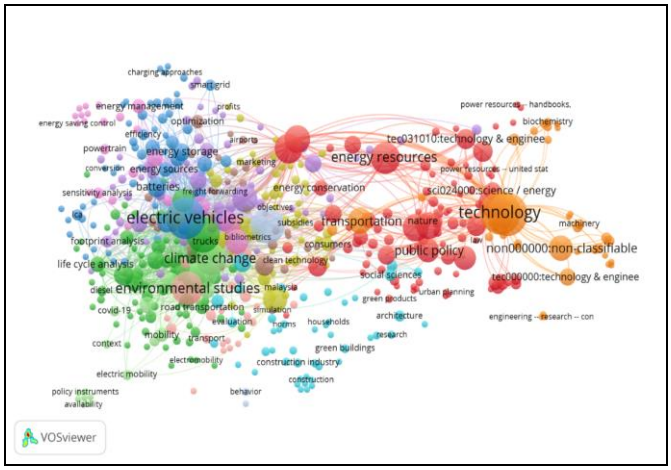


Fig. 12 Bibliometric network of the most cited keywords in Proquest

### *G. Analysis of the types of vehicles most studied in the databases*

Statistically, a progressive growth is evidenced in the last twelve years, this is reflected in the trend expressed in Figure 13; likewise, it is visualized that the composition of these trends is occupied in its great majority (74%) by electric vehicles of the pure electric category.

In the results of the search for technologies applied in the reduction of the carbon footprint, it was found that in the last few years there was an increase in the number of researches referring to pure electric vehicles and plug-in hybrid electric vehicles. On the other hand, Ref [26] indicated that, to increase the performance of strategies with respect to efficiency, degradation, fuel economy and greenhouse gas reduction, 21.59% of the strategies have as their main objective to increase the efficiency of electric vehicles and 6.29% in optimizing performance and reducing emissions. Ref [27], determined that electric vehicles are a new research trend both in the field of sustainable development and circular economy, since sustainability promotes a feasible strategy to achieve continuous development of the economy, society and the environment.

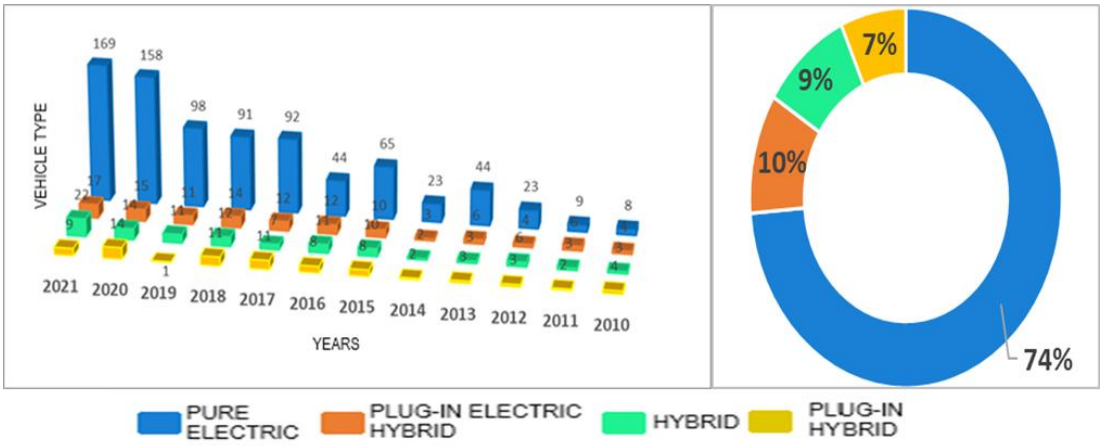


Fig. 13 Trend of vehicle types used in databases

*F. Analysis of the most representative articles in the databases*

In the present bibliometric analysis, 17 research papers published between the years 2010 to 2021 were reviewed, where it was found that the most researched electric vehicle is the pure electric vehicle (see Table 1).

TABLE I
AMOUNT OF $CO_2$ EMITTED BY ELECTRIC VEHICLES

| Nro. | Type of electric vehicle | kWh | km | gCO2 emitted | % emissions | Authors |
|---|---|---|---|---|---|---|
| 1 | BEV | 16.8 | 100 | 38.1 | 17% | [28] |
| 2 | PHEV | 3.1 | 100 | 153.2 | - | [29] |
| 3 | BEV | 5.6 | 100 | 9.8 | - | [30] |
| 4 | BEV | 10 | 100 | 81 | 33% | [31] |
| 5 | PHEV | 10 | 100 | 74 | 19% | [31] |
| 6 | BEV | 21.2 | 100 | 231 | - | [32] |
| 7 | BEV | 14 | 100 | 109.2 | - | [33] |
| 8 | BEV | 12 | 100 | 208.3 | - | [34] |
| 9 | BEV | 17.2 | 100 | 163.9 | - | [35] |
| 10 | BEV | 17 | 100 | 110.35 | - | [36] |
| 11 | BEV | 17.3 | 100 | 194.017 | - | [13] |
| 12 | BEV | 21 | 100 | 198.7 | - | [37] |
| 13 | BEV | 17 | 100 | 95 | - | [38] |
| 14 | BEV | 19 | 100 | 155.09 | - | [39] |
| 15 | BEV | 15.6 | 100 | 117.7 | - | [30] |
| 16 | BEV | 19.9 | 100 | 282.7 | - | [40] |
| 17 | BEV | 19.6 | 100 | 138.72 | - | [41] |

Ref [42] states that the following formula should be used to calculate the CO2 emitted by a fossil fuel vehicle:

$$EP = KRV\ x\ FE_p$$
$$EP = 100\ x\ 15.6 = 1560$$

Where:

Ep = Total emissions of pollutant p (gCO2).
KTV = Kilometers traveled per vehicle
EFp = Emission factor of pollutant p

With the above mentioned, it is calculated that on average the CO2 emission of an electric vehicle per 100km traveled is 138g CO2, while that of a traditional combustion vehicle is 1560g CO2, which shows that electric vehicles reduce the carbon footprint by 91% on average.

As for the results obtained from the emissions of electric vehicles, they have been marketed as zero-emission vehicles, favoring urban air quality. The statement is not accurate if we include emissions from electricity production in power plants and vehicle manufacturing, showing that the total amount of GHG emissions from the EV is only lower than emissions from the conventional vehicle. Energy consumption and GHG emissions depend critically on the source of electricity, and energy use and emissions can be reduced when the electricity comes from nuclear and renewable energy [32].

## IV. CONCLUSIONS

The bibliometric analysis showed that the use of electric vehicles is efficient in reducing the carbon footprint given that the average percentage of emissions is almost zero; however, due to the high economic value and the lack of recharging stations, its implementation is being delayed in most countries. Among the most relevant results are:

The amount of research that studied the use of electric vehicles as an alternative to reduce the carbon footprint was 1017 documents, of which 410 belong to the Scopus database, 184 to Web of Science, 142 to Science Direct and 281 to Proquest.

The journals with the highest scientific production regarding the use of electric vehicles for carbon footprint reduction are "Energies" with 54 publications in the Scopus, Web of Science and Proquest databases. Also, the "Journal of Cleaner Production" with 53 publications in the Web of Science, Scopus and ScienceDirect databases.

The countries with the highest scientific production on the use of electric vehicles are the USA with 306 papers (30%), followed by the UK with 128 papers (12%) and China with 98 papers (10%).

Four types of electric vehicles were identified which are pure electric vehicle, plug-in hybrid electric, plug-in hybrid and hybrid. From these, the most researched is the pure electric.

The use of electric vehicles greatly reduces the impact of carbon footprint. This is due to the implementation of new technologies such as rechargeable batteries that are used in vehicles, being one of the most efficient alternatives for reducing the carbon footprint.

## ACKNOWLEDGMENTS

The authors would like to thank "Investiga UCV" of the Universidad César Vallejo for financial support for the publication of this research.

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