

Electric vehicles: a bibliometric analysis and a detailed view

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Abstract

Seen by many as a major technological advance, hybrid and electric cars are not new to the market. They were once strong competitors of conventional automobiles, but for reasons that will be explained in this study, they were passed over and had a marginal participation in the history of the automobile since the 1930s. In this article, we carry out a bibliometric analysis and an extensive survey of scientific publications on electric vehicles. The Web of Science and Scopus databases were used. Electric vehicles were first published in 1922 in the Scopus database, while in WoS the first study was published in 1966. In the bibliometric analysis, different performance metrics were extracted, such as: total articles, total citations and citation per article. In addition, top 10 of the most productive and highly cited authors, main subject areas, sources or journals, countries and institutions are evaluated. A list of highly influential articles is also evaluated. Subsequently, a detailed discussion of the most cited articles and a classification by a ranking of one to ten is carried out. This article used the study by Pranab, Shukla and Abraham (2019) as a basis to structure the analyses.

Keywords: bibliometric study; Web of Science; SCOPUS; electric vehicles.

Veículos elétricos: uma análise bibliométrica e uma visão detalhada



Resumo

Vistos por muitos como um grande avanço tecnológico, os carros híbridos e elétricos não são novidade no mercado. Eles já foram fortes concorrentes dos automóveis convencionais, mas, por razões que serão explicadas neste estudo, foram negligenciados e tiveram uma participação marginal na história do automóvel desde a década de 1930. Neste artigo, realizamos uma análise bibliométrica e uma extensa pesquisa de publicações científicas sobre veículos elétricos. Foram utilizados os bancos de dados Web of Science e Scopus. Os veículos elétricos foram publicados pela primeira vez em 1922 no banco de dados *Scopus*, enquanto no *WoS* o primeiro estudo foi publicado em 1966. Na análise bibliométrica, foram extraídas diferentes métricas de desempenho, como: número total de artigos, número total de citações e citações por artigo. Além disso, são avaliados os 10 autores mais produtivos e altamente citados, principais áreas temáticas, fontes ou periódicos, países e instituições. Uma lista de artigos altamente influentes também é avaliada. Posteriormente, é realizada uma discussão detalhada dos artigos mais citados e uma classificação de um a dez é feita. Este artigo utilizou o estudo de Pranab, Shukla e Abraham (2019) como base para estruturar as análises.

Palavras-chave: estudo bibliométrico; Web da Ciência; SCOPUS; veículos elétricos.

1 INTRODUCTION

Electric vehicle technology is not characterized as a recent technological innovation, contrary to what many believe. Electric vehicles were strong competitors of internal combustion automobiles, since since the 1930s, their participation is marginal in the history of the automobile. However, the North American automobile industry expresses a greater number of launches of hybrid and electric vehicles, currently, purely electric (Baran; Legey, 2011). The authors also point out that these changes were due to the fact that many relevant technological advances in today's electric vehicles, such as digital technologies, more resistant modern batteries, that is, there were no major changes in current electric motors, nor in the use of kinetic energy generated. by the vehicle. The promotion of electric vehicles is added to the policy of transforming a fossil energy economy into a sustainable economy, based on renewable energies (Baran; Legey, 2011).

Discussions around electric vehicles have increased significantly in recent years, due to some factors, including pollution, as transport is responsible for 25% of all CO emissions worldwide (Murray; Carmeliet; Orehounig, 2020)

However, despite electric passenger vehicles having increased from around 17,000 units in the year 2010 to over 10 million in 2020, they still represent a small share of passenger car registrations, which are equivalent to 4.2% in 2020. including battery electric vehicles and hybrid electric vehicles (Seelarbokus, 2021).

There are several relevant factors that influence the choice of purchasing electric vehicles, especially technical factors, which cover vehicle attributes such as: maximum acceleration speed, autonomy, battery life, availability and performance of the charging infrastructure; economic factors, refer to vehicle purchase price, fuel economy, insurance value, lifetime expenses and supporting policies; environmental factors, include reduced air pollutant emissions, and other externalities such as noise reduction. Among them, what stands out the most are economic factors, as they play a crucial role in the choice of electric vehicles compared to vehicles with an internal combustion engine (Danielis *et al.*, 2020).

However, one must take into account the emergence of the “energy efficiency paradox” or “energy efficiency gap” (Gillingham *et al.*, 2009). The use of electric vehicles will begin in large metropolises, which already need an intense electric charge. Thus, the new need for charging

charging for electric vehicles will represent a huge challenge for the urban electricity grid (Wang et al., 2021).

The Brazilian energy matrix has production led by hydroelectric energy (64.9%), followed by wind (8.6%), biomass (8.4%) and solar (1.0%) (Dos Santos *et al.*, 2021). The author also reports that with the increase in demand on electricity due to the use of electric vehicles, it will entail a possible social cost, that is, it will be necessary for the government to invest in energy adequacy (Dos Santos *et al.*, 2021).

Therefore, for the dissemination of electric vehicles to occur, an appropriate electric charging infrastructure is also necessary, requiring many investments in infrastructure. Thus, the electrical distribution network must be organized to serve the consumer and generate stimuli for them to recharge their vehicle without overloading the electrical system (Castro *et al.* 2021). To analyze more data on electric vehicles this study will perform a bibliometric analysis.

Bibliometric or scientometric analysis is the field of study that helps to analyze current trends in literature related to a given field and provides guidelines and impetus for future research work. this basically provides an overview and general structure of the study area. Earlier, Pritchard (1969) and Broadus (1987) gave us a precise definition of bibliometric research.

Later, Heck and Bremser (1986) extended their work by carrying out an analysis of authors and organizations in the field of accounting. Recently, several researchers have analyzed several emerging topics such as heuristics (Loock and Hinnen, 2015), big data (Huang *et al.*, 2015; Prathap, 2013), decision support of support systems (Arnott and Pervan, 2005), (Arnott and Pervan, 2005), (Blanco-Mesa *et al.*, 2016) real-time operating systems (Shukla *et al.* 2018, in addition to bibliometric analysis.

The main contributions of the article are highlighted as follows:

- A detailed bibliometric analysis on "Electric Vehicles" was carried out in the Web of Science (WoS) and Scopus databases;
- Research growth is documented annually;
- Popular parameters such as: highly productive authors, most influential authors, most cited discipline, highly prolific countries and institutions were discussed and showed the top 10 in each of them;
- The top 40 articles are listed based on the total citations received to date (26/08/2022);
- The visualization of the most common keywords in the field of electric vehicles, extracted from the two indexing platforms, is displayed;
- In addition to the complete bibliometric study, the main conclusion of all documents indexed in the WoS repository and articles cited at least 10 times in Scopus was also discussed.

The rest of the article is structured as follows: Section 2 describes the data collection process and methodology used in this article. Detailed and extensive bibliometric analysis is carried out in Section 3. We provide a detailed bibliographic survey of recent years in Section 4. Section 5 concludes the article by summarizing the results.

2 RESEARCH METHOD

In this state-of-the-art study, we collected bibliometric data from two of the most referenced repositories: Web of Science (WoS) and Scopus. Therefore, the results of these two databases are compared for all different scientific output growth queries. The keyword used for the search query was: "Electric Vehicles" for WoS and Scopus, and the search was performed on August 26, 2022.

Two of the most commonly used standard indices in computer science were used and the engineering community indices were considered, which are: Expanded Science Citation Index (SCI-E) and Social Science Citation Index (SSCI). From WoS and Scopus, we retrieved various tags such as: author, title, abstract, country, citation record, author affiliation, etc. While

WoS extracted 13,119 documents, Scopus showed 90,175 documents. Of the documents extracted in WoS, 89.21% are articles, on the other hand, in Scopus, 38,845 productions are classified as articles, which represents only 43.07% of the total documents. The other main category was Conference Papers, which was 53.01% (47,795).

In this article, several performance indicators were extracted for bibliometric analysis. Total Papers (TP), which is the total number of publications from the source, Total Citations (TC), which is the total number of citations received by the publication, and Citations per Paper (CPP), that is, the total number of citations received, divided by total publications. In most tables, "R" indicates rank.

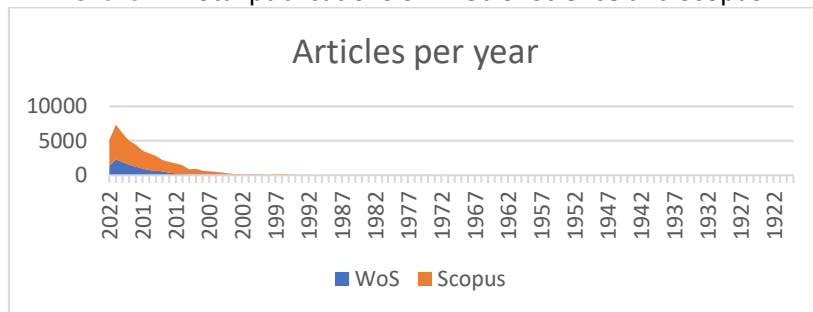
3 BIBLIOMETRIC ANALYSES

In this section, we show the bibliometric results for the various performance parameters such as: research growth, who is the most productive author and highly cited authors, most sought after discipline, top journals, country reviews, reviews by institutions, and highly influential articles in " Vehicles Electrics".

3.1 RESEARCH GROWTH

Electric vehicles were first published in 1922 in the Scopus database, while in WoS the first study was published in 1966. Figure 2 shows the total number of publications in WoS and Scopus. Later, after the year 2002, it increased exponentially until reaching a maximum of 7212 December 2021 in Scopus and 2134 in WoS. The total number of scientific articles in WoS and Scopus is shown in Chart 1. According to WoS, the number of citations was maximum in 2017, which is likely to increase over time. In both bases, 2022 was a year of decrease in production, for Mede and Schafer (2022) this decline can be explained by the COVID-19 pandemic.

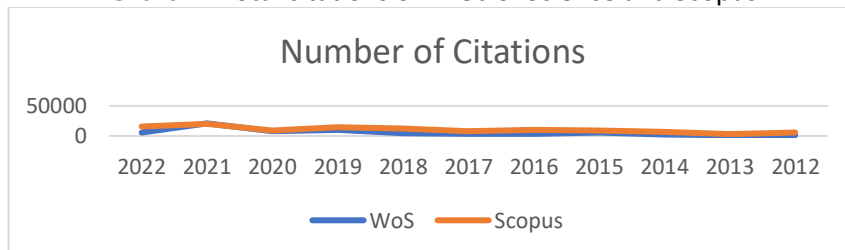
Chart 1 - Total publications on Web of Science and Scopus



Source: Authors (2022).

The total number of citations counts in WoS and Scopus is shown in Chart 2, where the graph of the number of citations per database since 2012 is shown. According to WoS, the number of citations was maximum in 2022, even result for Scopus.

Chart 2 - Total citations on Web of Science and Scopus



Source: Authors (2022).

3.2 MOST PRODUCTIVE AND MOST CITED AUTHORS

The most productive authors for WoS and Scopus are extracted and ranked based on the number of publications. The list of the top 10 most productive authors is shown in Table 1. Fujimoto and Ouyang are the highest contributors in both databases; with 132 publications in WoS and 143 publications in Scopus respectively.

Table 1 - Ranking of the authors with the highest production

R	WoS			Scopus				
	Authors	TP	TC	CPP	Authors	TP	TC	CPP
1	Fujimoto, Hiroshi	16	121	7,56	Ouyang,m	18	231	12,83
2	Xiong, Rui	14	102	7,29	He, H	16	165	10,31
3	Ouyang, Minggao	14	33	2,36	Xiong, r	16	49	3,06
4	Wang, Zhenpo	12	67	5,58	Hu,x	14	55	3,93
5	He, Hongwen	12	25	2,08	Qin,d	14	41	2,93
6	Hori, Yoichi	11	61	5,55	Chen, L	12	21	1,75
7	Chau, Kwok Tong	10	45	4,50	Luo,y	10	15	1,50
8	Van Mierlo, Joeri	9	32	3,56	Anon	9	31	3,44
9	Emadi, Ali	8	11	1,38	Emadi, A	9	23	2,56
10	Lin, Cheng	7	9	1,29	Li,k	9	20	2,22

Source: Authors (2022).

In WoS, Fujimoto is followed by Xiong, Ouyang and Wang, with 102, 75, 73 and 70 publications, respectively. There are three authors in the top 10 list in the 6-10 ranking, whose TP is less than 10. These authors are: Joeri (TP=9, R=8), Ali (TP=8, R=9), Cheng (TP =7, R=10). From Scopus database, Ouyang is followed by He and Xiong, both with 16 publications, but HE has a higher TC. Two other authors ranked 1-5 have 14 TP, they are Hu and Qin, but the author Hu has a TC greater than Qin. Anon, Ernadi and Li have 9 publications each, the same amount as the author R=8 in the Web of Science, more than the most productive author in WoS. Interestingly, four authors in the top 10 and only Emadi have the same ranking in both bases.

3.3 DISCIPLINE WISE ANALYSIS

Both repositories, WoS and Scopus, allocate relevant subject categories to papers in their indexing list. The 10 main areas of study in the two databases are listed in Table 2. WoS and Scopus have Engineering (Engineering) as the TOP 1 of 7,481 and 29,870 publications, respectively. After that, both have the energy area ("Energy") TP of 3724 in WoS and 12621 in Scopus. It has other areas common to both databases, although their classification is different, such as: Computer Science (TP = 1177 and R =5 in WoS, TP = 6809 and R= 3 in Scopus). In addition to publications in the obvious areas, there has been a lot of work in several other disciplines due to the energetic debates of today. As we can see social science and business publications in both bases.

Table 2 - Top 10 subject areas covered by electric vehicles

R	WoS			Scopus		
	Area	TP	%	Area	TP	%
1	Engineering	7481	35%	Engineering	29870	41%
2	Energy	3724	18%	Energy	12621	17%
3	Transportation	2432	11%	Computer Science	6809	9%
4	Environmental Science	1372	6%	Mathematics	5437	7%
5	Computer Science	1177	6%	Environmental Science	5412	7%
6	Mathematics	1065	5%	Management	3577	5%
7	Social Sciences	1036	5%	Social Sciences	3486	5%
8	Telecommunications	1012	5%	Physics abd Astronomy	2594	4%
9	Thermodynamics	983	5%	Chemistry	2008	3%

10	Chemistry	891	4%	Business	1181	2%
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Source: Authors (2022).

Furthermore, in both bases, productions in the area of social sciences reach an average of 5%. The % (contribution) for both databases exceeds 100% as there would be more than one category in which an article can be categorized. An interesting observation that can be concluded from Table 3 is the greater coverage of studies on electric vehicles. This also shows the much broader integration of interdisciplinary work from various disciplines such as business, management and accounting, social sciences, operations research, etc., in addition to computer science and engineering.

Table 3 presents the 10 main sources or journals that publish most frequently in the area studied in this article. A "journal" is a publication with a fixed term with publication with the aim of promoting and monitoring the progress of the discipline/area that it represents (PRANAB et al, 2019).

Table 3 - The top 10 journals that publish the topic of electric vehicles

R	WoS			Scopus		
	Journal	TP	%	Journal	TP	%
1	Energies	1201	24%	Energies	1689	20%
2	Applied Energy	907	18%	Applied Energy	1002	12%
3	Energy	891	18%	World Electric Vehicle Journal	887	11%
4	IEEE Access	437	9%	Energy	865	10%
5	Journal Of Power Sources	399	8%	IEEE Access	840	10%
6	IEEE Transactions on smart grid	344	7%	IEEE Transactions On Vehicular Technology	833	10%
7	Transportation Research Part D Transport And Environment	241	5%	Journal Of Power Sources	830	10%
8	Sustainability Switzerland	225	4%	IEEE Transactions On Industrial Electronics	517	6%
9	Sustainability	220	4%	Transportation Research Part D Transport And Environment	487	6%
10	Journal Of Cleaner Production	218	4%	Sustainability Switzerland	480	6%

Source: Authors (2022).

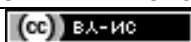
In WoS, Energies newspaper has the highest number with a total publication of 1201, followed by Applied Energy with 907 publications. However, the maximum citation count is achieved by Energy with a citation count of 58291. At Scopus, the two journals are the same as Web of Science, with 1689 and 1002 productions respectively. Unlike WoS, Energies newspaper has the highest number of TC. In both bases, journals with R between 1 and 5 give priority to works in the area of engineering and computing.

3.4 COUNTRY ANALYSIS

From the data extracted, the top 10 most productive countries in terms of the number of publications, both from WoS and Scopus, are presented in this section. Table 4 shows the order of countries ranked by TP, and CPP. In WoS, China leads the list with 4530 publications, followed by the US and UK with 2377 and 792 publications, respectively.

Table 4 - The 10 countries with the highest production volume of electric vehicles

R	WoS			Scopus		
	Country	TP	CPP	Country	TP	CPP
1	China	4530	38%	China	13.594	42%
2	USA	2377	20%	USA	6.320	20%
3	Reino Unido	792	7%	Reino Unido	2.171	7%



4	Coreia do Sul	750	6%	Coreia do Sul	1918	6%
5	Índia	717	6%	Alemanha	1892	6%
6	Canada	671	6%	Índia	1804	6%
7	Alemanha	654	5%	Japão	1656	5%
8	Irã	494	4%	Canadá	1568	5%
9	Itália	468	4%	Itália	1297	4%
10	Austrália	450	4%	França	1012	3%

Source: Authors (2022).

In the Scopus list, China is again in the 1st position with 13594 with a CPP of 42%, almost with an index of half of the productions, again as in the institutions, China represents the country with the greatest interest in the area studied. Germany is also followed by the United States of America, the United Kingdom and South Korea as in WoS. Only France, Japan, Iran and Australia are not present in the two bases in the analysis of R 1-10.

3.5 INSTITUTION WISE ANALYSIS

In the two databases, WoS and Scopus, the analysis institutions with the top 10 organizations that publish articles is compiled in Table 5. The first ranking is acquired by the Beijing Institute of Technology with 426 works in WoS and 1185 works in Scopus, this institution Chinese is ranked 361st among the best universities in the world, in 2010 it reached 43,991 students and then only grew, it is cited in Haidian district. After that, Tsinghua University, located in Beijing, capital of China, has 346 articles indexed in WoS and 1048 in Scopus. The third best ranked institution differs between the bases. In WoS, the University of California System, an American university created in 1968, which has R=3 and TP=275. Regarding Scopus, the one with R=3 has TP=659, which is the Chongqing University, located in Chongqing, another institution located in China, showing the interest of Chinese institutions in the Area.

Table 5 - The 10 main institutions that publish the theme of electric vehicles

R	WoS			Scopus		
	Institution	TP	%	Institution	TP	%
1	Beijing Institute of Technology	426	16%	Beijing Institute of Technology	1185	19%
2	Tsinghua University	346	13%	Tsinghua University	1048	16%
3	University of California System	275	10%	Chongqing University	659	10%
4	United States Departamento of Energy	262	10%	Tongji University	576	9%
5	Chongqing University	248	9%	Ministry of Education China	575	9%
6	Tongji University	233	9%	Jilin University	565	9%
7	Jiangsu University	231	9%	Shanghai Jiao Tong University	520	8%
8	Harbin Institute of Technology	228	8%	Harbin Institute of Technology	431	7%
9	Southeast University	226	8%	Southeast University	422	7%
10	Shanghai Jiao Tong University	212	8%	Jiangsu University	399	6%

Source: Authors (2022).

Among the Lists, only four institutions are not present in the two databases. The University of California System (R=3) and United States Department of Energy (R=3, TP=262), both American institutions that appear in WoS and not in Scopus. In relation to it, the institutions that are not listed in the Top 10 of WoS are: Ministry of Education China (R=5, TP=575), and Jilin University (R=6, TP=565) both Chinese institutions. In general, the institutions are Chinese or American, these are the two countries with predominance in the ranking of the ten institutions with the highest volume of productions.

3.6. RANKING HIGHLY INFLUENTIAL PAPERS

This section lists the 10 most cited works in WoS and Scopus. Table 6 and Table 7 present the name of the article, authors, number of citations, year and newspaper of those ranked between 1 and 10.

Table 6 - Ranking of the most cited authors in WOS

R	Authors	Title	Source Title	TC
1	Yilmaz, M and Krein, PT (2014)	Review of Battery Charger Topologies, Charging Power Levels, and Infrastructure for Plug-In Electric and Hybrid Vehicles	IEEE TRANSACTIONS ON POWER ELECTRONICS	1476
2	Li, SQ and Mi, CC (2015)	Wireless Power Transfer for Electric Vehicle Applications	IEEE JOURNAL OF EMERGING AND SELECTED TOPICS IN POWER ELECTRONICS	1015
3	Kang, JW et al (2017)	Enabling Localized Peer-to-Peer Electricity Trading Among Plug-in Hybrid Electric Vehicles Using Consortium Blockchains	IEEE TRANSACTIONS ON INDUSTRIAL INFORMATICS	995
4	Budhia, M et al (2013)	Development of a Single-Sided Flux Magnetic Coupler for Electric Vehicle IPT Charging Systems	IEEE TRANSACTIONS ON INDUSTRIAL ELECTRONICS	871
5	Nykvist, B and Nilsson (2015)	Rapidly falling costs of battery packs for electric vehicles	NATURE CLIMATE CHANGE	823
6	Martinez, CM et al (2017)	Energy Management in Plug-in Hybrid Electric Vehicles: Recent Progress and a Connected Vehicles Perspective	IEEE TRANSACTIONS ON VEHICULAR TECHNOLOGY	782
7	Mi, CC et al (2016)	Modern Advances in Wireless Power Transfer Systems for Roadway Powered Electric Vehicles	IEEE TRANSACTIONS ON INDUSTRIAL ELECTRONICS	654
8	Ding, SH; Liu, L and Zheng (2017)	Sliding Mode Direct Yaw-Moment Control Design for In-Wheel Electric Vehicles	IEEE TRANSACTIONS ON INDUSTRIAL ELECTRONICS	541
9	Hannan, MA (2018) et al	State-of-the-Art and Energy Management System of Lithium-Ion Batteries in Electric Vehicle Applications: Issues and Recommendations	IEEE ACCESS	539
10	Bakker, S et al (2014)	The influence of financial incentives and other socio-economic factors on electric vehicle adoption	ENERGY POLICY	522

Source: Authors (2022).

In WoS, the article by Yilmaz and Krein (2014) obtained the highest number of citations of 1476, as it provided a review of battery charger topologies, presenting important details about electric vehicle charging. This article is preceded by Li and Mi (2014) with 1015 citations, the article also talks about charging electric vehicles, but with a wireless technology. Regarding the articles by R 1-10, all are from the last ten years, starting from 2013 with the article by Budhia et al (2013) with R=4 to Hannan et al (2018) with R=9. In short, the articles present the battery or load as a central point. Table 7 of the appendix presents the most influential articles indexed in Scopus with publication source, authors' names and year of publication.

Table 7 - Ranking of the most cited authors in SCOPUS

R	Autores	Titulo	Periódico	TC
1	Lu, L.et al (2013)	A review on the key issues for lithium-ion battery management in electric vehicles	Journal of Power Sources	3038
2	Clement-Nyns, K., Haesen, E., Driesen, J.(2010)	The impact of Charging plug-in hybrid electric vehicles on a residential distribution grid	IEEE Transactions on Power Systems	2175
3	Yilmaz, M., Krein, P.T. (2013)	Review of battery charger topologies, charging power levels, and infrastructure for plug-in electric and hybrid vehicles	IEEE Transactions on Power Electronics	1791
4	Chan, C.C.(2007)	The state of the art of electric, hybrid, and fuel cell vehicles	Proceedings of the IEEE	1447
5	Li, S., Mi, C.C. (2015)	Wireless power transfer for electric vehicle applications	IEEE Journal of Emerging and Selected Topics in Power Electronics	
6	Wang, C.-S., Stielau, O.H., Covic, G.A. (2005)	Design considerations for a contactless electric vehicle battery charger	IEEE Transactions on Industrial Electronics	1231
7	Khaligh, A., Li, Z. (2010)	Battery, ultracapacitor, fuel cell, and hybrid energy storage systems for electric, hybrid electric, fuel cell, and plug-in hybrid electric vehicles: State of the art	IEEE Transactions on Vehicular Technology	1218
8	Cano, Z.P., et al (2018)	Batteries and fuel cells for emerging electric vehicle markets	Nature Energy	1176
9	Nykvist, B., Nilsson, M. (2015)	Rapidly falling costs of battery packs for electric vehicles	<u>Nature Climate Change</u>	1127
10	Chau, K.T., Chan, C.C., Liu, C. (2008)	Overview of permanent-magnet brushless drives for electric and hybrid electric vehicles	IEEE Transactions on Industrial Electronics	1115

Source: Authors (2022).

Lu *et al.* (2013) cited 3038 times in Scopus and is at the top of the list, followed by Clement-Nyns, Haesen, Driesen (2010) and Yilmaz and Krein (2013) with a citation count of 2175 and 1791, respectively. These are the three articles whose citation count is greater than 1500. All other articles on the list have citations greater than 1000. Unlike the WoS list, Scopus articles R1-10 have some productions that are more than ten years old, they are: Stielau, O.H., Covic, G.A. (2005); Chan, C. C. (2007); Chau, K.T., Chan, C. C., Liu, C. (2008); Khaligh, A., Li, Z. (2010) and Clement-Nyns, K., Haesen, E., Driesen, J. (2010).

3.8. TOP MOST KEYWORDS IN WOS AND SCOPUS

In this section, use your tool for Vviewer, which is an OS view used to select keywords used by authors in papers. As can be seen, how research on electric vehicles in short uses terms related to energy, technology and batteries. Graph 1 shows the network of the most common keywords indexed in the Web of Science. Graph 2 provides a visualization of the most popular keywords used by authors in Scopus. Almost all of the keywords emanating from electric vehicles in Scopus are common to keywords in the Web of Science.

In the network, as in Graph 1, six predominant clusters can be seen, the main one corresponds to the words listed in the Electric Vehicles group in green with 125 items, then the second cluster in red with 76 items and keywords such as charging and energy. The third cluster, in green, with 59 items, has words like traction motors and controllers.

4 ELECTRIC VEHICLES: OVERVIEW OF THE MOST RELEVANT PRODUCTIONS OF THE THEME

In this section, we will discuss what the authors have tried to achieve in relation to electric vehicles. The most cited articles presented above were used. This section provides the reader with the rationale and technologies used by various researchers in recent times in relation to electric vehicles.

4.1 PERSPECTIVES ON ELECTRIC VEHICLES

There are many studies that present perspectives on electric vehicles, dealing in general with batteries, charging and the market. Nykvist and Nilsson (2015) analyze in their study how the prospects for electric vehicles should be evaluated. The authors believe that to properly assess the prospects of commercially competitive battery electric vehicles (BEVs), one needs to have accurate information about the current and expected cost of batteries. The literature reveals that costs are falling, but with great uncertainties about the past, current and future costs of the dominant lithium-ion technology. As a result, it is shown that cost estimates across the industry fell by approximately 14% per year between 2007 and 2014, from over US\$1,000 per kWh to around US\$410 per kWh, and that the cost of batteries used by manufacturers of market-leading BEVs is even lower, at \$300 per kWh, and has declined by 8% per year.

According to Martinez *et al.* (2017), the second most cited article in this area, plug-in hybrid electric vehicles (PHEVs) offer an immediate solution for reducing emissions and fuel displacement within the current infrastructure. Aiming at PHEV powertrain optimization, a multitude of energy management strategies (EMSs) have been proposed. While these algorithms present various levels of complexity and accuracy, they encounter a limitation in terms of availability of information from future trips, which often prevents exploitation of the full PHEV potential in real-life cycles.

Mi *et al.* (2016) presents a perspective regarding the charging of electric cars. For the authors, wireless electric vehicles based on the wireless power transfer system (WPTS), classified into road-powered electric vehicles (RPEVs) and stationary charging electric vehicles (SCEVs), are in the spotlight as future means of transport. conventional transport.

RPEVs are free from serious battery issues like large, heavy and expensive batteries and long charging times because they get their power directly from the road as they move. The power transfer capability, efficiency, lateral tolerance, electromagnetic field, air gap, size, weight and cost of WPTSs have been improved by virtue of innovative semiconductor switches, better coil designs, road construction techniques and higher operating frequency. Recent advances in WPTSs for RPEVs are summarized in this review article. Fifth and sixth generation online electric vehicles, which reduce the cost of infrastructure to market, and interoperability between RPEVs and SCEVs are covered in detail in this article.

Ding *et al.* (2017) address the perspectives in relation to the automatic control system and what it can present in terms of better stability of electric vehicles in critical situations. In this paper, direct yaw-moment control strategies are proposed for wheeled electric vehicles using slip mode (SM) and non-linear perturbation observer (NDOB) techniques. The ideal skid angle at the center of gravity and yaw rate are first calculated based on a two-degree-of-freedom linear vehicle model. Then the actual slip angle is identified and estimated by constructing a state observer. Controllers are tested and the best for electric vehicles is presented.

4.2 TECNOLOGIC INNOVATION

Regarding technological innovation, Cano *et al.* (2018) initially present a view on electric vehicles, for the authors today's electric vehicles are almost exclusively powered by lithium-ion batteries, but there is still a long way to go before electric vehicles become dominant in the global automotive market. The authors present battery innovations from hydrogen cell-powered to lithium-ion batteries. Three sectors that are not well served by current lithium-ion electric vehicles are discussed, namely the long-range, low-cost, high-utilization transport markets. The technological properties that must be improved to fully enable these electric vehicle markets include specific energy, cost, safety and grid compatibility. Six energy storage and conversion technologies that have varying combinations of these enhanced characteristics are compared and evaluated separately for each market.

Clement, Haesen and Driesen (2010) present technological innovations in relation to hybrid electric vehicles. For the authors, hybrids will be popular vehicles by 2030. The batteries of these plug-in hybrid electric vehicles must be charged at home in a standard outlet or in a corporate parking lot. These extra electrical loads have an impact on the distribution network which is analyzed in terms of energy losses and voltage deviations. Without charging coordination, vehicles are charged instantly when connected or after a fixed departure delay. This uncoordinated power consumption on a local scale can lead to network problems. Therefore, coordinated charging is proposed to minimize energy losses and maximize the load factor of the main grid. The optimal charging profile of plug-in hybrid electric vehicles is calculated by minimizing energy losses. As accurate forecasting of domestic loads is not possible, stochastic scheduling is introduced. As innovation proposals, two main techniques are analyzed: quadratic and dynamic programming.

Li and Mi (2014) analyze the benefits of charging electric vehicles wirelessly. Wireless energy transfer (WPT) using magnetic resonance is the technology that can be a technological breakthrough and free the human being from wires. WPT technology has been developing rapidly in recent years. At the kilowatt power level, the transfer distance increases from several millimeters to several hundred millimeters with a grid-to-load efficiency of over 90%. The advances make WPT very attractive for electric vehicle (EV) charging applications in both stationary and dynamic charging scenarios. Battery technology is no longer relevant in mass market penetration of EVs. It is hoped that researchers can be encouraged by the state-of-the-art achievements and drive the development of the WPT as well as the expansion of the EV.

Nykvist and Nilsson (2015) believe that with growing concerns in our environment, there is a growing interest in electric vehicles (EVs) and hybrid EVs (HEVs) from automakers, governments and customers. As electric drives are the core of EVs and HEVs, it is a pressing need for researchers to develop advanced electric drive systems. In this article, an overview of permanent magnet (PM) brushless (BL) drives for EVs and HEVs is presented, with an emphasis on machine topologies, drive operations, and control strategies. Then, three major research directions of PM BL drive systems are elaborated, namely the external rotor PM BL drive system with magnetic gear, the PM BL integrated start generator system and the electrical transmission system.

4.3 CHARGING SYSTEMS

Charging systems is a topic much discussed in both Scopus and WoS. Yilmaz and Krein (2014) believe that on-board charging systems can be either conductive or inductive. An external charger can be designed for high charging rates and is less limited by size and weight. Level 1 (convenience), level 2 (primary), and level 3 (fast) power levels are discussed in the article. Future aspects such as roadbed charging, energy level chargers and infrastructure configurations are presented, finally these points are compared and evaluated based on the amount of energy, charging time and location, cost, equipment and other factors.

Lu, L. *et al.* (2013) present analyzes on charging modes. Compared to other commonly used batteries, lithium-ion batteries are characterized by high energy density, high power density, long service life and environmental friendliness, and thus have found wide application in the field of electronics. However, lithium-ion batteries for vehicles have high capacity and large parallel serial numbers, which, together with issues such as safety, durability, uniformity and cost, impose limitations on the wide application of lithium-ion batteries in the vehicle. The narrow area in which lithium-ion batteries operate safely and reliably requires effective control and management of the battery management system.

The study by Lu *et al.* (2013) presents, through literature review and in combination with practical experience, a brief introduction to the composition of the battery management system (BMS) and its main problems, such as battery cell voltage measurement, battery state estimation, battery uniformity and equalization, battery failure diagnosis and so on, in hopes of providing some inspiration for the design and research of the battery management system.

The study by Yilmaz and Krein (2013) analyzes the current status and implementation of battery chargers, charging energy levels and infrastructure for plug-in and hybrid electric vehicles. Charger systems are categorized into off-board and on-board types with unidirectional or bidirectional power flow. Future aspects such as roadbed loading are presented. Various power level chargers and infrastructure configurations are presented, compared and evaluated based on the amount of power, charging time and location, cost, equipment and other factors.

For Budhia *et al.* (2013) inductive power transfer is a practical method for recharging electric vehicles because it is safe, convenient and reliable. For the authors, the performance of magnetic couplers that transfer energy determines the overall viability of a complete system. Circular couplers are the most common topology in the literature; however, they have fundamentally limited coupling. Both topologies can be designed and operated to ensure compliance with international guidelines.

Wang, Stielau and Covic (2005), despite being one of the first articles, still presents current results. This article reviews theoretical and practical design issues related to inductive power transfer systems and verifies theory developed using a practical electric vehicle battery charger. The project focuses on the approaches needed to ensure energy transfer across the entire operating range of the system. As such, a new approach to primary resonant circuit design is proposed, where deviations from design expectations due to phase or frequency shift are minimized. Of particular interest are systems that are neither loosely nor strongly coupled. The developed solution depends on the selected primary and secondary resonant topologies, magnetic coupling coefficient and secondary quality factor.

4.4 FINANCIAL ANALYSIS RELATING TO THE ELECTRIC VEHICLE MARKET

Kang *et al.* (2017) proposed a peer-to-peer (P2P) electricity trading model for local buying and selling of electricity between plug-in hybrid electric vehicles (PHEVs) in smart grids. Unlike traditional schemes, which transport electricity over long distances and through complex electricity transmission grids, our proposed model achieves demand response by providing incentives to offload PHEVs to balance local electricity demand outside their own interests. Numerical results based on a real map of Texas indicate that the dual auction mechanism can achieve social welfare maximization while protecting the privacy of PHEVs.

Khaligh and Li (2010) address the fuel economy and all-electric range (AER) of hybrid electric vehicles (HEVs), where they are highly dependent on the vehicle's on-board energy storage (ESS) system. Energy storage devices charge during low power demands and discharge during high power demands, acting as catalysts to provide increased energy. Batteries are the main energy storage devices in land vehicles. As a result, they present the financial benefits of each charging model.

4.5 SUSTAINABILITY

Chan (2007) presents an environmental view of the transport market, despite being a 2007 article, the study still presents current views. The author points out that with stricter regulations on emissions and fuel economy, global warming and energy resource constraints, electric, hybrid and fuel cell vehicles have increasingly attracted the attention of automakers, governments and customers. Research and development efforts have focused on developing new concepts, low-cost systems, and reliable hybrid electric powertrain. This article reviews the state of the art of electric, hybrid and fuel cell vehicles. Topologies for each category and enabling technologies are discussed, analyzing the environmental bias of each topology and seeking to present justifications for reducing the use of fossil fuels.

5 FINAL CONSIDERATIONS

In this article, a detailed bibliometric analysis was carried out in the field of electric vehicles. It sought to discover the growth of productions since the first publication. Bibliometric analysis helped to uncover the structures and developments in this area. For the bibliometric analysis, two widely used repositories were used, such as: WoS and Scopus. While WoS extracted 13,119 documents, Scopus showed 90,175 documents. Fujimoto is the most produced author on the Web of Science, while Ouyang is the largest on Scopus.

Engineering and Energy are the areas of study that are most targeted on the subject in both databases. Journal Energies is the most productive journal in the bases, journals with R1-10 are similar in both bases. China and the United States of America are the most productive countries on electric vehicles, while the Beijing Institute of Technology in China is the institute with the highest number of publications.

The bibliometric analysis in this article provided the intrinsic structure of the publications. This is a much-needed study for the field of electric vehicles so that the research community can probe the publication hierarchy in this area.

After the bibliometric analysis, the main articles classified based on the total citations are analyzed. Then, the visualization of the most common keywords in the indexed databases is presented. Finally, the contribution of publications in WoS and Scopus is widely discussed. Overviews of published works have been categorized into several subsections that would help the reader to get an overview of their different application areas. The limitation of this study is that the bibliometric study provides the number of articles and their citations. However, numbers represent quantity, but citations do not mean quality. In addition, we cover widely used WoS and Scopus for bibliometric study, however there are some other sources that include open access journals. Thus, further analysis with other indexing bases, such as Google Scholar, can be considered as a future scope of this study.

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