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Perspectives and Challenges of Vehicle Electrification: An Academic Review

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ABSTRACT

Advances in technology have undoubtedly brought enormous benefits to society. On the other hand, these same advances bring new and even unknown impacts to the environment. When the theme is transportation systems, electric vehicles are the most modern and technological, being considered by the mainstream media as the most environmentally sustainable transportation model. However, little is discussed regarding the impacts and harms that are tied to this type of vehicles. In this way, this study aims at highlighting the main challenges and perspectives of the vehicular electrification technology, through a systematic review on the topic. The results obtained point out that electric cars may be responsible for the increase of eco-toxicity not only with respect to air quality, but also water and metal depletion. And, it also highlights, the existence of other technologies as alternatives to vehicle electrification.

Keywords: Electric Vehicles, Challenges, Perspectives, Environmental Impact.

Perspectivas e Desafios da Eletrificação Veicular: Uma Revisão Acadêmica

RESUMO

Os avanços da tecnologia vêm trazendo enormes benefícios para a sociedade, indubitavelmente. Por outro lado, esses avanços trazem consigo novos e até mesmo desconhecidos impactos ao meio ambiente. Quando o tema é sistemas de transportes, os veículos elétricos são o que há de mais moderno e tecnológico, sendo considerados pelas principais mídias como o modelo de transporte ambientalmente mais sustentável. No entanto, pouco se é discutido com relação aos impactos e malefícios atrelados a estes tipos de veículos. Desta forma, este estudo tem por finalidade destacar os principais desafios e perspectivas da tecnologia de eletrificação veicular, através de uma revisão sistemática sobre o tema. Os resultados apontam que os carros elétricos podem ser responsáveis pelo aumento da eco-toxicidade não apenas no que diz respeito à qualidade do ar e da água, mas também na depleção de metais. E, destaca a existência de outras tecnologias como alternativas à eletrificação veicular.

Palavras-chave: Veículos Elétricos, Desafios, Perspectivas, Impacto Ambiental.

Introduction

Controlling the emission of greenhouse gases (GHG) is a challenge nowadays. Several agreements have been formalized on a global scale, such as the United Nations Framework Convention on Climate Change (UNFCCC, 1992), the Kyoto Protocol (1998), and the Copenhagen Accord (2009). The transportation sector, which contributes 14% of direct greenhouse gas (GHG) emissions worldwide (IPCC, 2014), has become a focus of environmental concern worldwide. This sector is responsible for, on average,

25% of the CO₂ emissions of the planet. In 2007, 63% of the total of these emissions were attributed to passenger cars (Perujo et al., 2011). Nevertheless, the potential transport sector is considered as one of the most likely to present possibilities to reduce GHG emissions. Also, as reported by Costa et al. (2015), a higher intensity of vehicle traffic was associated with a condition of increasing the amount of harmful gases released into the atmosphere. More recently, due to factors driven by the COVID-19 pandemic, such as social isolation and economic depression, it was possible to observe a decrease in the growth rate of

the vehicle fleet, which reverberated in a decrease in air pollution (Souto, 2020). This pollution reduction corroborates the “criminalization” of internal combustion vehicles (ICV).

The replacement of ICV with less or non-pollutant vehicles stands out as a possible solution to mitigate part of the emission of GHGs. Electric vehicles (EV) are a better option to mitigate this environmental problem. However, several issues related to the energy efficiency, economic viability, and environmental impacts of the EV should be appropriately addressed before the choice of the best solution to the environment and society. One must consider both the impacts of the electric transport models, as well as those from the vehicles powered by fossil fuels. In this study, vehicle cost, life service of the cars and their components, other pollution risks (air and soil pollution), availability of electric energy, and the levels of emissions required to generate electric energy are addressed, in addition to other socio-economic aspects.

Much attention is paid to the relationship between EV and the reduction of air pollution, and little care is given to the production of other forms of pollution related to these vehicles such as lithium battery scrap, dangerous and particular waste of electrical and electronic equipment (WEEE). In the universe of the EVs, another point to be addressed is the source of energy generation in the country's electric matrix (Shi et al., 2020). As the traditional electric grid supplies the vehicles, it is necessary to know if the source of generation of this energy is non-polluting. Otherwise, only the source and location of the pollutant emissions will be changing.

In this context, the following research questions emerged: (i) how the scientific community has been addressing the issue of environmental impact related to the dissemination of electric vehicles? (ii) what is the main published research? (iii) How did these researches reverberate over time? Therefore, the main objective of this study is to carry out a systematic review of the main aspects, both positive and negative, with emphasis on the environmental impacts associated with the use of electric vehicles and their components.

Internal combustion vehicles

The invention of internal combustion engines dates from the mid-19th century. Despite the improvements in the last decades, these engines generate polluting gases as a by-product due to the incomplete combustion of hydrocarbons (Elavarasan et al., 2019). Most of the engines in these cars operate

in four stages: intake, compression, expansion (explosion), and discharge. The car engine combines atmospheric air with fuel, generating an exothermic chemical reaction that causes the gases to expand in the combustion chamber, pressing on the piston, which descends, generating a rotary movement in the engine, transforming heat into work. The gases generated in the combustion process such as carbon monoxide and dioxide (CO and CO₂), sulfur dioxide (SO₂), nitrogen oxides (NO_x), hydrocarbons (HC), and particulate materials (PM) are eliminated by opening the discharge valve. The rotation movement of the engine induces the generation of an electric current in the vehicle alternator that is stored in lead-acid batteries (Ecycle, 2016).

The proper management of lead-acid batteries scrap is another environmental challenge related to the ICVs. Exposure to the harmful effects of improper handling of lead-acid battery scrap is widespread in developing countries, where there is an illegal market for lead recycling. This illegal market and its harmful effects on the environment and public health are described in Paoliello and De Capitani (2007), Haefliger et al. (2009), He et al. (2009), Chen et al. (2009), Trivelato and Paoliello (2009), Gupt (2014), Noguchi et al. (2014), Gupt and Sahay (2015), and Daniell et al. (2015). Among all the components of the lead-acid battery, lead is considered the most dangerous, because it is a potent neurotoxin that can affect the health and intellectual development of children and adults and can cause many neurological disorders (Van Der Kuip et al., 2013). Lead-acid battery scrap has high market value because it can be 100% recycled and reused as an input for the manufacture of new batteries (Cspower, 2009).

Electric vehicles

Considered the innovation of the 21st century, according to BBC (2016), the electric car appeared at the same time as the first vehicles (with internal combustion engine) and has already represented 30% of the North American market. The first energy-powered vehicle was developed in France in an adaptation made in a buggy in 1881. However, the first automobile designed to run as an electric car was developed in the United States in 1890 (BBC, 2016).

The history of electric cars has always been related to the history of batteries. In 1859, the Belgian Gaston Planté demonstrated the first lead-acid battery. Despite the low autonomy of these vehicles, due to the low energy storage capacity of their

batteries, the EV was very successful because they were considered technologically superior to the others. According to Hoyer (2008), electric car manufacturers used to be monopolists and sought to sell expensive products to consumers with high purchasing power, adopting a sales strategy focused on the social status provided by the electric vehicle. Over time, the production and distribution of electricity have not kept pace with the development of combustion vehicles and were still incipient in many regions. Gasoline could be easily transported anywhere in the world. Also, the low autonomy of EVs has become an obstacle to their development. While the EVs have a range of 80 Km for new battery recharging, the ICVs make an average of 320 Km with 80 L of fuel (BBC, 2016). According to Baran (2012), while the combustion vehicle (CV) industries continued with aggressive commercial strategies focused on mass sales, lower prices and greater autonomy of their vehicles, the EV market maintained its vehicles as luxury products, produced on small scales and with low autonomy until ICVs gradually replaced them.

Electric vehicles can be classified into two major groups: (i) purely electric vehicles (EV), powered only by electric motors, whose energy is stored in batteries typically of lithium and originated from the electricity supply network; and (ii) hybrids, which combine electric motors with internal combustion engines. Hybrid vehicles (HEV) are all those that, in addition to an electric motor, also have a combustion engine. Combustion engines can be used exclusively to charge the batteries or to be co-responsible for the traction of the vehicles, dividing the task of propelling them with the electric motors and, at the same time, charging the batteries. Vehicles using a propulsion system with a combustion engine will determine their degree of hybridization. The level of influence of the combustion engine on the propulsion system of these vehicles is what will determine their degree of hybridization. The combination of the two types of engines in a hybrid vehicle makes the car more efficient, adding less fuel consumption since the electric motor is assisting the combustion engine (Benajes et al., 2019).

According to Itemm (2016), the lowest degree of hybridization is found in vehicles called micro and mild, in which there is no power feed through the electrical network. The so-called micro hybrids, also known as start-stop, turn off the car engine whenever it is stopped and start again whenever requested by the driver (when stepping on the accelerator, for example). Mild vehicles, by start-stop technology, use a regenerative braking system in

which the battery is recharged from the car kinetic energy, allowing the electric motor to act together with the combustion engine to provide power to the vehicle. The leading battery technology used in the micro and mild hybrids is the lead-acid battery due to its cost-benefit and because it is always operating next to the combustion engine. The vehicles with the highest degree of hybridization are the full and plug-in hybrid electric vehicles (PHEV). Considering these two types of vehicles, the electric motor, through the energy provided by the battery, must be able to drive the car without the aid of the combustion engine. In this case, the battery becomes much more demanded and needs to have a higher energy density. Therefore, the most widely used battery technology is lithium-ion. The main difference between these two technologies is that, in the plug-in vehicle, the battery not only uses the combustion engine for its recharge but also can recharge from an external source (Itemm, 2016).

Among plug-in vehicles, there are purely electric vehicles that have only the electric motor as a propulsion system. Although the mechanical structure of a 100% electric vehicle is greatly simplified, the vehicle requires investments in infrastructure, such as refueling stations and a prepared charging network. As the plug-in vehicles are, for the most part, fueled by the electric network, they still need long recharge time, from 6 to 12 hours, although the practice of recharging opportunities is already familiar (Jatoba, 2014; Kumar et al., 2020).

EVs may be associated with some form of pollution, although they do not emit GHG during their operation. The EVs are supplied through the traditional electrical network and, to be considered vehicles that do not emit GHG, the energy used to recharge them must come from a clean energy source. Otherwise, CHG will be emitted in the energy generation process and, consequently, indirectly, in the use of EVs. In China, 85% of the energy matrix is based on fossil fuels, of which 90% has coal as a heat source. In this country, power generation plants are often far from large consumer centers. Ji et al. (2012) highlight that EVs by not directly emitting polluting gases during their operation would be contributing to a false impression of sustainability. There is a transfer of pollution from the richest central areas to the most impoverished rural areas. This study discourages the adoption of EVs, as they would be increasing the emissions of CO₂ and other pollutants, increasing the number of deaths due to respiratory problems in China. The authors also reinforce that a large part of this problem is due to the inefficiency in the country's energy generation. Possibly, the results would be

different in countries with a cleaner energy matrix. Other environmental impacts from EVs are related to the production of extremely toxic electronic waste (battery scraps) and the country's electrical matrix.

Regarding batteries, EVs typically use lithium batteries that contain, in their constitution, heavy and toxic metals, with the aggravating factor that there is still no consolidated process for their recycling. According to Afonso et al. (2015), recycling a primary lithium battery presents a risk due to the possibility of fire and explosion due to lithium and the non-aqueous solvent. Attempts to open them can expose batteries to moisture in the air, causing violent reactions. In the critical stage of the mechanical opening of the battery (crushing), the processes use the chemical element Argon in liquid form or ovens with a high ventilation rate. Due to its high degree of instability, the risk is also present during the operation of these batteries. Lithium accumulators require a high degree of embedded electronics to ensure that there are no under- or overloads, which, if they occur, can lead to the explosion of the batteries.

Material and methods

In a first search, the database aggregating platform EBSCO Host® was chosen as the primary research tool. The EBSCO Host® is one of the main leading aggregators of scientific journal databases in the world, offering a set of more than 375 databases secondary research and full text, allowing a simultaneous search in all databases. On the EBSCO Host® platform, the term "electric vehicle" was inserted, and, as a result, 31 databases appeared. The Web of Science (WoS) database showed the largest number of articles related to the topic and was chosen as the second research instrument. In the WoS database, obtained in the first search, the term "environmental impact" was inserted, and, within the results obtained for the term, the new terms "electric vehicle" and "environmental impact" were inserted together. With the help of Mendeley® and Citespace® softwares, the articles in the second search were divided into related themes to facilitate the study and understanding of the results.

The flowchart shown in Figure 1 summarizes the methodology used in the research platforms.

Figure 1: Methodological flowchart

The results were defined through data obtained and analyzed following the steps: reduction, display, and conclusion/verification.

Results and discussions

The results obtained were ordered by degree of relevance. When selecting the "relevance" filter in the search tool, the records are automatically sorted in descending order based on a classification system that considers how many of the search terms are found in each record. The highest-ranked records appear at the top of the list. The classification of the relevance of the source records considers the title, abstract, and keywords of the articles in the database.

"Electric vehicle" term

Using the EBSCO Host® platform, in the advanced search options, the "Find all my search terms" mode was selected in order to find articles specifically containing this approach and strict use of these words. Keywords were chosen in the English language, as it is predominant in scientific publications in the area of interest. And, the relevance filter was selected in order to order the results obtained.

The first articles published using the term "electric vehicle", registered in the EBSCO database, date from 2006. Among these initial studies, the article by Zhao (2006), "Whither the Car? China's Automobile Industry and Cleaner Vehicle

Technologies” addressed the problems related to pollutant emissions in China, highlighting the importance of thinking about the development of cleaner transport technologies, aiming to balance the challenges of economic development, environmental protection, and energy security. Still were highlighted, as main obstacles to this change, aspects related to Chinese policies, the high costs of manufacturing cleaner vehicles, and the low immediate economic benefits were also highlighted.

After 2008, the annual number of articles containing the term “electric vehicle” surpassed the number of 100 publications in the EBSCO database. Hence, this year was chosen as the landmark starting point for the beginning of this literature review. In 2008, there were 189 publications. Almost a decade later, in 2017, that amount reached 545 (Figure 2).

Figure 2: Quantity of articles containing the term “electric vehicle” in EBSCO platform from 2007 to 2018.

Figure 2 shows that the years with the largest number of articles containing the term “electric vehicle” were 2016 and 2017, with 323 and 546 registers, respectively. Among them, the considered most relevant are summarized in Table 1.

Table 1: Most relevant articles with the term “electric vehicle” from 2008 to 2018.

Author/Year	Title	Core themes
Schneider et al. (2014)	The Electric Vehicle-Routing Problem with Time Windows and Recharging Stations	Planning EV recharge routes to avoid inefficient routes with long detours
Imani et al. (2018)	Impact Evaluation of Electric Vehicle Parking on Solving Security-Constrained Unit Commitment Problem	Evaluation of the impact of recharging electric vehicles on the safety of electricity supply network
Adepetu et al. (2017)	Relative importance of price and driving range on electric vehicle adoption: Los Angeles case study	The price of EV as the most significant barrier to its adoption in large scale
Nejad et al. (2017)	Online scheduling and pricing for electric vehicle charging	Development of online scheduling and pricing mechanism for EV recharging according to load demand
Lin et al. (2016)	Multi-objective optimization design for a battery pack of electric vehicle with surrogate models	In this investigation, presented with an optimization design framework based on systematic substitutes for electric vehicle batteries
Ramos et al. (2015)	A self-adapting similarity-based coalition formation approach for plug-in electric vehicles in smart grids	Deals about Vehicle-To-Grid (V2G) as the integration of electric vehicles in smart grids
Kim et al. (2014)	Recycling process of spent battery modules in used hybrid electric vehicles using physical/chemical treatments	Physical-chemical treatments for recycling lithium-ion battery modules used in hybrid electric vehicles

Lindgren et al. (2015)	Identifying bottlenecks in charging infrastructure of plug-in hybrid electric vehicles through agent-based traffic simulation	The effect of different charging infrastructure configurations on the autonomy of plug-in hybrid electric vehicles
Sheikhan et al. (2013)	State of charge neural computational models for high energy density batteries in electric vehicles	Hybrid electric vehicles as an alternative to environmental concerns due to increasing demand for gasoline
Li (2018)	Literature review of tire-pavement interaction noise and reduction approaches	The problem of tire-pavement interaction noise as a trend of the advent of electric vehicles
Wu et al. (2012)	Investigation on Litio batteries developed for hybrid electric vehicle	The anodic carbon-coated nano-Lithium material evaluated with the LiNiCoMnO cathode for potential application in hybrid electric vehicle batteries

The areas of interest most present in the search for the term “electric vehicle” were: Electrical Engineering and Multidisciplinary Sciences, which are directly related to studies on environmental pollution, energy generation and storage technologies, in addition to issues related to social impacts. On the EBSCO platform, the databases with the largest number of articles published with the term “electric vehicle” were: Web of Science (WoS); Science Direct; and Academic Search Complete. Therefore, it was decided to carry out the other researches using the WoS database directly.

The countries with a higher number of articles published with the term “electric vehicle”, were: China, United States, Germany, South Korea, Canada, and Japan, respectively. The author which showed the largest number of published papers is Minggao Ouyang (72 papers), from Tsinghua University, in Beijing. Most of his publications that about EV deal with the Energy consumption, and has the most cited article “Thermal runaway mechanism of lithium-ion battery for electric vehicles: A review” (with 226 citations). Ying Li (59 papers), from Delft University of Technology, Netherlands, is the second author with the most published work on the topic and has the most cited article “Business innovation and government regulation for the promotion of electric vehicle use: lessons from Shenzhen, China” (with 51 citations).

However, even though the most-cited authors are from other institutions/countries, concerning the research centers with the higher number of publications using the term “electric vehicle”, the Beijing Institute of Technology, in China, occupied

the position leading the ranking, with 409 publications in the period 2008-2018.

“Environmental impact” term

When the new search was performed in the WoS database, the filters of strict use of the keyword, in English, and the ordering by relevance were again used, using only the term “environmental impact”, during the period from 2008 to 2018, the years with the largest number of articles containing the research term were 2017 and 2018, with 21,553, and 19,990 records, respectively (Figure 3).

Figure 3: Number of articles with the term “environmental impact” in the WoS database, from 2008 to 2018.

Environmental Sciences and Environmental Engineering stand out as the main areas of interest of the authors and their studies that were published in the WoS database. Through Table 2, we can observe the diversity of themes present in the most relevant

articles with the term "environmental impact" during the period from 2008 to 2018.

Table 2: Most relevant articles with the term "environmental impact", from 2008 to 2018.

Author/Year	Titles	Core themes
Djekic (2015)	Environmental Impact of Meat Industry – Current Status and Future Perspectives	Overview of the environmental impact of the meat chain
Shafie et al. (2013)	Environmental Health Impact Assessment and Urban Planning	Urban planning as an impact system for environmental health
Wang et al. (2012)	Environmental Impact Post-Assessment of Dam and Reservoir Projects: A Review	The Post-Assessment Environmental Impact Study (EIPA) as a research tool for dams and reservoirs projects
Ali et al. (2015)	Environmental Life Cycle Assessment of a Residential Building in Egypt: A Case Study	Use of life cycle assessment (LCA) tools to assess the environmental impacts of residential buildings
Morales et al. (2010)	Ei scale - an environmental impact assessment scale related to the construction materials used in the reinforced concrete	Environmental impact assessment scale, related to construction materials used in the production of reinforced concrete structures
Chang (2014)	Research gaps related to the environmental impacts of electronic cigarettes	It considers research gaps related to the environmental impacts of electronic cigarettes due to their manufacture, use, and disposal
Lebret (2015)	Integrated environmental health impact assessment for risk governance purposes; across what do we integrate?	The Integrated Environmental Health Impact Assessment (IEHIA) as an element in the third phase of environmental risk management
Susanto et al. (2018)	Risk assessment method for identification of environmental aspects and impacts at Ore processing industry in Indonesia	Identification of environmental aspects and impacts to assess risks, opportunities, and severity in ore processing industries
Fagan et al. (2015)	European multi-level environmental governance in a post-conflict context: the gradual development of environmental impact assessment processes in Bosnia-Herzegovina	Identification of factors that allow or prevent the development of multi-level environmental governance at the levels of state and subnational entities in Bosnia and Herzegovina
Alghazo et al. (2018)	E-waste environmental and information security threat: GCC countries vulnerabilities	Current e-waste management practices in Gulf Cooperation Council (GCC) countries, including the volume of e-waste generated, disposal, and reuse/recycling practices

Still, with the help of the existing filters on the search platform, it was possible to verify the information provided below.

The countries with the largest number of articles containing the term “environmental impact” in the WoS database, were The United States (3,911 publications), China (2,755 publications), Italy (2,407 publications), Spain (2,133 publications), England (1,844 publications), Brazil (1,430 publications), Germany (1,252 publications) and Australia (1,055 publications). Unlike the first term searched for this topic, Brazil was in the ranking of countries with the most publications, occupying the sixth place.

Concerning research centers that study this topic, the following stood out in the number of publications: the University of California System, located in the USA and the Center National de la Recherche Scientifique, which is the largest public scientific research institution in France, and one of the largest in the world.

The author which showed the largest number of publications related to the keyword “environmental impact” was Yu Zhang (63 publications, with a total of 1,539 citations), from Xi'an University of Technology, located in the city of Xian, in Shaanxi, China. Zhang had as the most cited article the research entitled “The relationship between energy-resource depletion, climate change, health resources and the environmental Kuznets curve: Evidence from the panel of selected developed countries” carried out in partnership with Khan et al. (2016), in which they examined the relationship between depletion of energy resources, climate change, health resources and the Kuznets environmental curve (EKC), under the financial constraint environment in the panel of developed countries selected during the period 2000-2013.

The second most prominent author was Yue Li, from Peking University in Beijing, also in China. In the WoS database, his study pointed out as the most relevant was the “Greening of the Earth and its drivers” carried out in partnership with Zhu (2016), in which he addressed the change in the dynamics of terrestrial vegetation with consequences for the functioning of the terrestrial system and the provision of ecosystem services, due to the various environmental changes at a global level related to polluting agents, such as fertilizers.

“Electric vehicle” and “Environmental impact” terms

A simultaneous search using the strict terms “electric vehicle” and “environmental impact” in the WoS database, without the time filter, only 133 articles were found. The first one was published in 1993. A decade after, six articles were published. In the decade subsequent (2004-2013), 19 studies were published. The number of articles published per year only surpassed the dozen in 2014, when 22 surveys were published. According to WoS records, there was no publication in the years 2011, 2009, 2004, 2000, 1999, 1997, 1996, 1995, and 1994. As of 2008, 122 articles were published, all in English (Figure 4). The United States, Italy, and China were, in that order, the countries with a higher number of publications indexed in the WoS database. It is important to highlight that, during the period from 2008 to 2018, only 10 countries addressed the topic, using these two keywords (Figure 5).

Figure 4: Number of articles with the terms “electric vehicle” and “environmental impact” in the WoS database, from 2008 to 2018.

Figure 5: Countries in which articles with the terms “electric vehicle” and “environmental impact” in the WoS database, from 2008 to 2018.

Considering different countries, 24 authors had more than one publication, highlighting three

authors with more articles published (Dincer, I.; Messagie, M.; and Van Mierlo, J.), with five articles each. Considering the research institutions with more than one publication, in a total of 33, the Institute of Technology at the University of Ontario (Ontario Tech University), in Canada, stands out. Also, followed by five publications, Vrije Universiteit Brussel, from Brussels, Belgium. Two Brazilian institutions are on the list: Federal University of Paraíba (UFPB) and Federal Technological University of Paraná (UFTPR), occupying the 160th and 162nd positions, respectively.

Figure 6: The 10 institutions with the most publications, containing the terms "electric vehicle" and "environmental impact" in WoS, from 2008 to 2018.

The article considered most relevant was that of Tartakovsky et al. (2015) of the Faculty of Mechanical Engineering, in Israel, entitled "Modeling environmental impact of cybernetic transportation system" which addressed the concept of cyber cars (electric vehicles associated with an intelligent network system), comparing the performance of this type of vehicle with the conventional vehicles, thereby estimating their environmental impact. Table 3 presents a summary of the evolution of the main themes addressed in the articles indexed from 2008 to 2018, simultaneously involving the terms "electrical vehicle" and "environmental impact".

Considering 122 articles investigated with the terms "electrical vehicle" and "environmental impact", 70 are related to Engineering, 46 to Energy Fuels, 44 to Environmental Sciences and 77 to other areas reinforcing the multidisciplinary aspect of these studies (Figure 7).

Figure 7: Research areas of publications, containing the terms "electric vehicle" and "environmental impact" in the WoS database, from 2008 to 2018.

Related themes

The related themes that appear in a complementary way to the central terms were classified into three specific categories: (i) energy generation and storage (25 articles), (ii) charging stations (65 articles), and (iii) economic impact (23 articles).

Related articles to energy generation and storage, with some association with the energy that supplies the EV generation or storing, were looked for using the Mendeley® software; 25 articles were found, whose most prominent keywords were: "electricity generation mix" and "battery".

Among such studies, the article of Casals et al. (2017) entitled: "Electric vehicle battery reuse: stands out between the most relevant articles, as well as the one from Preparing for a second life", in which the authors identified the high potential for contamination of the lithium battery (battery model most used for energy storage in EV), and showed the complexity of the recycling process, suggesting the reuse of these batteries in other applications. Since even though they no longer have enough charge density to power an EV, that is, they are at the end of their useful life for this application, such batteries may still have sufficient charge density for other diverse uses, mainly in the area of electronics in which less energy is usually required. As an example, such batteries could be remanufactured to manufacture notebook batteries.

Table 3: Most relevant articles containing, simultaneously, the terms "electrical vehicle" and "environmental impact", from 2008 to 2018.

Author/Year	Titles	Core themes
Tartakovsky et al. (2015)	Modelling environmental impact of cybernetic transportation system	The Cyber Transport System (CTS) and its environmental impacts
Casals et al. (2017)	Electric vehicle battery reuse: Preparing for a second life	The second life of electric vehicle batteries as a means of mitigating impacts and economic opportunity
Vidhi et al. (2018)	A review of electric vehicle lifecycle emissions and policy recommendations to increase EV penetration in India	The life cycle of an EV, its impact on emissions and policy recommendations for the Indian market
Yuan et al. (2017)	Method for evaluating the real-world driving energy consumptions of electric vehicles	Use of the neural network to determine EV performance in real driving conditions
Zhao et al. (2017)	The Projected Pathways and Environmental Impact of China 's Electrified Passenger Vehicles	The use of projected routes and EVs as tools to reduce environmental impacts
Li et al. (2016)	Electric vehicle charging in China's power system: Energy, economic and environmental trade-offs and policy implications	The transfer of the use of gasoline to the generation of coal energy for use in EVs
Zheng et al. (2018)	Manufacturing decisions and government subsidies for electric vehicles in China: A maximal social welfare perspective	The government's role in creating subsidies to promote EV and its environmental and social benefits
Van Mierlo et al. (2017)	Comparative environmental assessment of alternative fuelled vehicles using a life cycle assessment	Comparative assessment of vehicles powered by alternative sources, using a life cycle assessment
Messagie et al. (2013)	Environmental and financial evaluation of passenger vehicle technologies in Belgium	The environmental impacts and financial costs of different vehicle technologies, considering an everyday Belgian driver
Moriarty et al. (2017)	Can Electric Vehicles Deliver Energy and Carbon Reductions?	The eco-toxicity potential of EVs related to the quality of air, water, and metal depletion

About charging stations, studies dealing with the electrical infrastructure necessary to support the correct operation of electric vehicles were analyzed. Within this context, 65 articles were identified, whose

most associated keywords were: "charging infrastructure" and "recharging stations". The article highlighted was "An exploratory policy analysis of electric vehicle sales competition and sensitivity to

infrastructure in Europe”, (Harrison and Thiel, 2017), pointing out the need for one recharging point for every 25 electric vehicles, as is the optimal model for enabling new technology. It is important to emphasize that, in this study, the authors highlighted that higher numbers of recharge points versus the number of vehicles, than the one used as a reference, brings small gains and high costs. Through a field analysis carried out in European countries, it was observed by them that EV sales are relatively insensitive to levels of recharge points above one for every 10 vehicles.

Finally, concerning the category of economic impacts, looking to identify investigations related to conflicts and social impacts, motivated by economic interests, 23 articles were found. However, no convergence keywords were identified for the articles dealing with this topic. One of the studies that dealt with the theme was “The cost of electrifying private transport - Evidence from an empirical consumer choice model of Ireland and Denmark”, whose keyword associated with the theme was “socio-economic modeling”, while Mulholland et al. (2018) show that, despite the high policy of tax incentives, the absorption was low about EVs by the population. Taking into consideration that some countries, such as Ireland and Denmark, are in the process of removing the tax exemption currently in force, there should be an even greater retraction in EV sales in the future. Thus, sales of this type of automobile are expected to continue to decline as these incentives are reduced, characterizing electric vehicles,

increasingly, like luxury cars, restricted only to more prosperous people.

From the articles collected with the terms "electric vehicle" and "environmental impact" in the WoS database, and with the aid of the CiteSpace® software, a graphic analysis was generated (Figure 8), in which other themes were associated with these articles, defining a timeline for each one.

Through this analysis, it was found that one of the first topics to be addressed, with regard to electric vehicles, was about the analysis of the life cycle. The greatest repercussion of the subject occurred in mid-2013 (relevance characterized by the size of the circle, the larger the circle, the greater the repercussion based on the number of citations), and, as of 2016, the subject has lost focus.

Another aspect considered relevant is that, although they have not yet achieved great repercussion, the themes that stand out as more contemporary/current are: the growing concern linked to the problems arising from EVs - a subject that only started to have more prominence from 2010; The mix of power generation sources used to power the EVs - especially since mid-2009; and, issues related to the charging infrastructure of these vehicles - with greater prominence only from 2016.

In general, it is possible to diagnose that the theme of environmental impacts linked to vehicle electrification is a very contemporary issue, perhaps due to the scarcity of empirical data. Therefore, it needs to be further explored.

Figure 8: Timeline of the most prominent themes, using CiteSpace®.

The articles analyzed applying systematic review showed interactions regarding the influence of vehicular electrification on GHG emissions and the impacts of EVs on the electricity generation infrastructure. The authors show not only the benefits of EVs, but also the environmental impacts.

Van Mierlo et al. (2017) and Shi et al. (2020) emphasize that the environmental impacts of electric vehicles are strongly influenced by the source of electricity (gas, coal, nuclear, and renewables, such as wind, biomass and solar). The combination of electricity and the level of electrification is among the key factors that influence environmental performance.

Drivers use many accessories, and it influences the environmental impact of the EV. For example, the use of heating/cooling to reach the desired temperature has a significant influence on energy consumption (Egede, 2015).

In their investigative study, Li et al. (2016) considering the levels of EV penetration expected by 2030 in China, concluded that the implementation of EV essentially transfers the use of gasoline to the generation of coal-based energy (China's primary energy), leading to higher consumption of coal and, consequently, the increase in CO₂ emissions. Economically, EVs tend to outperform gasoline-powered vehicles in terms of average fueling costs,

because EVs tend to be powered by electricity produced by cheap, low-efficiency coal plants in regions where coal prices are low. The authors proposed an increase in the use of cleaner forms of electricity generation, associated with charging profiles that prevent the charging of these vehicles during peak periods. These results can support Chinese politicians to create efficient integration of the transport and energy system.

According to Van Mierlo et al. (2017), CO₂ emissions from an average European battery electric vehicle (BEV) vary between 2 g and 175 g CO₂/Km, depending on the electricity source and assumptions used. Relativizing these emissions per kWh consumed, Moro and Lonza (2017), considering the import/export of energy that occurs between the countries of the European Union (EU), reports that the carbon intensity of electricity used in the EU, in low voltage, in 2013, was 447 g of CO₂eq/kWh. One of the devices used in Belgium to reduce urban pollution due to emissions from power plants was to discharge the gases through tall funnels, taking the gases outside the city limits.

Sometimes comparing EVs with conventional vehicles is much more complicated than usually seems. Uncertainties occur both in the use of primary energy and in the calculation of greenhouse gas emissions. Besides, it may not be legitimate to evaluate these terms on a simple vehicle-Km basis, due to overflow effects. Moriarty and Wang (2017) state that EVs powered by the current European electricity mix offer a 10% to 24% reduction in global warming potential, compared to conventional diesel or gasoline vehicles. On the other hand, EVs have a potential for a significant increase in eco-toxicity, mainly affecting the quality of freshwater, generating its eutrophication, in addition to impacts related to metal depletion, mainly coming from the vehicle supply chain. The source of electricity, the consumption of energy during use, the lifetime of the vehicle, and the periodicity of replacing batteries were predominant to the results.

Authors define vehicle efficiency and state that it is not enough to compare the vehicle-Km per liter/kW of fuel/energy used. Comparing EV and conventional vehicles, both gasoline and electricity must be converted into primary energy - crude oil for combustion vehicles and coal for electricity from coal-fired power plants. Nevertheless, it is difficult for converting electricity into primary energy for different non-fossil fuels. In a network using 100% nuclear energy, the efficiency would be identical to a network using 100% hydroelectric energy, if calculated by some methods conventional in the

market, but less if the method of the International Energy Agency (IEA) was the one used. It is an unsatisfactory result that also makes the CV versus EV energy efficiency calculations arbitrary.

The problem identified previously can be avoided if comparisons between CV and EV are based on CO₂ or, more generally, GHG emissions, usually expressed as CO₂ equivalent. However, a new problem arises: in almost all published comparisons, electricity from non-fossil fuel (renewable and nuclear), it is assumed that these sources generate zero GHG, the so-called 'zero carbon' sources. It is true that these sources directly generate insignificant GHGs; the same cannot be said for its indirect emissions (Moriarty and Wang, 2017).

Regarding the overflow effect, Moriarty and Wang (2017) specifically examined existing EVs in Norway. Furthermore, they identified that EV acquisitions in the country were mainly due to the various taxes waived, as well as tolls and parking costs subsidized by the government. However, the authors found that most domestic purchases of electric vehicles are an addition to the domestic fleet, not as replacement vehicles. Therefore, there seems to be a negative spillover regarding the number of vehicles per household.

Regarding energy storage, Ruiz et al. (2018) evaluated aspects related to the safety of lithium-ion batteries (LIB). Events such as fires with laptops, cell phones, aircraft incidents, the withdrawal of products from the market (for example, Apple withdrew the lithium-ion packages from its PowerBook 5300 line, and EV Global Motors announced the recall of 2000 batteries in its electric bicycles) generate growing concern among the general public about lithium-ion technologies. It is natural that, over time, the battery cells degrade; however, in lithium batteries, this aging makes them more susceptible to explosion events, so the need for a firmly embedded electronics that controls the charge status of these batteries, preventing reach this state of charge.

According to Ruiz et al. (2018), the electrolytes used in LIB are mainly based on organic solvents, which are generally highly flammable. The most used electrolytes are mixtures of various carbonates (for example, propylene carbonate) and a dissolved salt (for example, lithium hexafluorophosphate (LiPF₆)). In the case of thermal leakage, the electrolyte breaks down, leading to the formation of gases. A greater danger is the presence of fluorinated and prismatic compounds, leading to the release of toxic and corrosive hydrogen. As some gases generated in high energy density events are

toxic, they can potentially cause severe damage to individuals.

According to Harrison and Thiel (2017), in the case of Brazil, the government's lack of support for infrastructure policies resulted in the slow implementation of EVs. The strategy adopted by the government through Inovar Auto (vehicle electrification incentive policy in Brazil) aims only at encouraging automobile manufacturers to produce more efficient cars concerning the emission of gases, without foreseeing, however, investments in infrastructure that support such initiatives. Currently, the Renault Zoé (France's most popular electric car), has a purchase price in Brazil four times higher than the purchase price in France due to the high import tax. Using this strategy, the government aims at encouraging national manufacturing, outsourcing the responsibility for vehicle electrification in the country, without worrying, as if it should, with the impact on issues related to power generation and with support related to charging stations.

According to the National Association of Motor Vehicle Manufacturers in Brazil (ANFAVEA, 2015), until August 2014, 558 electric vehicles were licensed in Brazil. The number is growing from less than 100 in 2012. Although the growth is not comparable with the countries of Europe and China, the issue of lack of infrastructure is already beginning to worry specialists in the area.

Nowadays, with the high purchase price of EVs, although the fuel cost is only about 10% of the similar combustion vehicle, the operating cost will be balanced if the car is driven over 3,000 Km per month. This target, in turn, is unlikely to be reached without an entire infrastructure spread throughout the cities. As the Brazilian government does not have a plan to implement financial support for public charging points, the establishment of these points will depend on investment by the private sectors. Given the inexistence of regulation on electric mobility charges established by the National Electric Energy Agency (ANEEL), which will serve as remuneration for energy trading companies, those that are investing in public charging stations, are doing so only field study, aiming at assessing the impact of electric vehicles on the local distribution network and also to learn how to develop and operate their charging network (Li, 2016).

It is also worth mentioning that when it comes to the infrastructure needed to support the deployment of EVs, it is also about the reliability of the energy distribution system. Once the electrical load increases, it is necessary that all cabling and support infrastructure is dimensioned to meet the

demand. Innovatively, Galiveeti et al. (2018) carried out a simulation based on a hypothetical residential area of 15 Km², in which the loads are served by a single substation designed for this purpose. The simulation carried out by the researchers, based on this representation, showed that the performance of recharges in random periods of electric vehicles, including peak hours, directly influences the reliability of the energy supply, to make the system's restoration capacity very slow, and the supply of energy, making it more prone to electrical failures, which can cause shutdowns.

In the uncontrolled recharge strategy, each car recharges immediately after accessing a charging location, the peak demand for electricity to charge electric cars occurs when the overall electricity demand is already high. During these periods, the additional electricity demand is typically covered by gas plants using fossil fuels. Therefore, the concept of introducing electric vehicles to reduce total carbon dioxide emissions can only be successful if combined with intelligent charging strategies (Ross and Guhathakurta, 2017).

Rosato et al. (2017) highlight that widespread adoption of EV would result in domestic electricity with radically different demand characteristics, representing a threat to the stability of the electricity grid. The European Community considers Micro-cogeneration and distributed generation as one of the most effective measures to save primary energy, reduce emissions, and reduce the impact of EV on the electricity grid. In Brazil, both micro and cogeneration initiatives, as well as those of distributed generation, are still very incipient.

In general, Ashnani et al. (2015) carried out a complete assessment of the fuel life cycle in gasoline, diesel, compressed natural gas, EV electric vehicles, and biodiesel vehicles. Comparing the different car technologies indicates that the climatic impact is considerably influenced by the vehicle's technology, the type of fuel, and the raw material used to generate the fuel. As recommended by the results, none of the options dominated the others in all dimensions. Given the combined effect of 1- the high share of fossils in the energy mix; 2- the low efficiency of electricity conversion technologies; and 3- the high weight of the battery bank, the performance of the EV is not considered to be satisfactory, not to mention the scraps of batteries that alone already represent a significant global impact. Biofuels filled the best position, given their CO₂ credits. Despite this, conventional biofuels are not without disadvantages, as they are costly and, in the current state, need considerable amounts of fossil resources.

Mallig et al. (2016) also bring as a diversification option the use of hybrid vehicles capable of associating benefits from more than one type of technology. Benajes et al. (2019) highlight that Hybrid electrics combine an electric battery with a combustion engine or generator. These solutions overcome range limitations and, at the same time, allow driving on electric power for most of the total mileage. It is also highlighted that such initiatives must be associated with plans to expand renewable energies.

Conclusions

The main findings of the study in question point out that the environmental benefit promoted by EVs is not an absolute truth. Although there are still few studies that emphasize the environmental challenges and impacts to be overcome by technology, the study demonstrated that this subject has been gaining more and more evidence in the scientific world and that the advantages attributed to electric vehicles are dependent on a series of factors, such as the participation of fossil sources in the energy generation mix, the low efficiency of the technologies for converting into electricity, the high weight of the battery banks, among other factors.

Also, it can be concluded that in fact, there is no technology considered at all to be the best option, since, for each region, there may be a more appropriate solution to local variables. Thus, of several technologies observed, among them, electrification, hybrid vehicles, those powered by biofuels, and even fossil fuels, fleet diversification is considered as the most viable alternative, since, in this way, it can be work in parallel with various realities.

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