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The role of the electrical vehicle in sustainable supply chains: a review

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Abstract. Environmental concerns, such as global warming and scarcity of natural resources, pressure companies to develop and adopt cleaner technologies and production processes. Besides, the search for sustainable development (as recommended by Agenda 2030 from the United Nations) has made companies rethink their whole supply chain, including transport activities. Besides, governments have been proposing public policies to obtain positive impacts in the economic, social and environmental dimensions. In this context, many studies have pointed out that electric mobility is a sustainable alternative to the transport sector and, in many EU countries, the government has bet on subsidies to attract manufacturers and customers to this market. Therefore, this paper aims to identify the role of electric vehicles (EV) in sustainable supply chains, considering the articles published in the Web of Science (WoS) database. We realize that there is a low quantity of papers dedicated to investigating the EV in this context. Many papers claim to perform sustainable analysis but do not evaluate the triple bottom line's three dimensions. Nevertheless, we identified that governments had developed policies to incentivize the introduction of electric vehicles in the market.

Keywords: electric vehicle, sustainability, supply chain.

1 Introduction

The last decades have been marked by growing concerns about energy usage and other environmental impacts [1], so we have experienced the development of policies to mitigate climate change, the proposition of actions to reduce the environmental impact and the discussion of renewable resources for energy sources in different sectors.

With the exponential growth of the population, the natural resources are being increasingly consumed and, therefore, the raw materials are becoming scarce and

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expensive [2]. In this context, companies have been pressured to act according to the sustainable development concept, which is understood as the development that meets the present's needs without compromising future generations [3]. This concern is not restricted to the company but extends to the entire supply chain and its activities [4].

Supply chains correspond to the entire management of a product useful life, from the extraction of raw material to its final disposal [4]. Therefore, the introduction of sustainability concept requires that the entire supply chain seeks more than the efficient management of processes, also considering innovative alternatives that improve environmental, social and economic conditions [5].

At this point, it is important to emphasize that, among the logistic activities performed in a supply chain, the transport is one of the most important, being responsible for the greater part of the costs, up to $\frac{1}{3}$ of the logistic costs [6].

From the environmental point of view, the transportation sector accounted for 45.4% of greenhouse gas (GHG) emissions and consumed about 32.7% of energy in Brazil in 2019, surpassing the industrial sector [7]. So, the transport sector contributes to the increase in global warming potential (GWP) and the scarcity of natural resources [8]. For this reason, this sector has been increasingly pressured to implement eco-friendly and sustainable strategies [9]. Sustainable strategies focused in this sector can be seen in [10-11].

In this context, many manufacturers of vehicles have sought to improve the technologies of internal combustion engines (ICE) to decrease GHG and pollutant emissions [12]. However, due to the increasing demand for vehicles and all the mentioned environmental problems, replacing ICE for electric vehicles (EV) have been raising as a possible solution [12], aiming to reduce both carbon emissions and dependency on fossil fuels.

It is important to emphasize that the concept of sustainability requires the triple bottom line, in other words, the assumption of the equal importance of the economic, social and environmental aspects. Only the joint analysis of these is possible to get sustainable strategies of energy resources [12].

Therefore, this paper aims to identify the role of the electric vehicle in sustainable supply chains, considering the articles published in the Web of Science (WoS) database. Assuming that electromobility is pointed by the literature to reduce the environmental impacts of the transportation sector, especially energy consumption of fossil fuels and carbon emission, we aim to understand if and how the discussion about sustainable supply chains is related to electromobility.

From this introduction, the article was divided into four sections: the theoretical framework about electric vehicles and sustainability (Section 2); the methodological procedures (Section 3); the presentation of the main findings (Section 4) and final considerations (Section 5). Finally, we have acknowledgments and references.

2 Theoretical Framework

There has been an increasing worry about sustainable development in order to reduce the impact in the environment in which we live and, thus, ensure the quality of life for future generations [13], and this is a main challenge in mobility sector. On the other

hand, the concept of sustainability is not always used correctly, as will be discussed in this paper. Many studies claim to analyze the sustainability of a certain product, process, or operation, but the social analysis is left aside, being performed only environmental and/or economic assessments [12, 14, 15, 16]. Nevertheless, to be considered sustainable, there must be a balance between the three pillars: economic, social and environmental [17].

Focusing on transport sector, sustainable transport has been an important challenge for many countries [10 - 11] to reduce air pollution, climate change, negative impacts on population life, energy consumption, material use, and provide better service with less cost. Papers concerned with improving sustainability in transport operations can be found in the literature, focusing in many countries, in Europe [18 – 19], in Brazil [15 – 16] and so on. In this context, many studies have bet on EVs as a sustainable alternative to ICE [20, 21, 17], although some of them emphasize the environmental pillar aiming at reducing the dependence on oil and carbon emissions [22].

In order to have greater acceptance of electric vehicles, it is necessary to provide information about their sustainability performance, because the impacts of increasing their use are unknown, especially regarding the materials and technologies used [8]. For example, many studies have pointed out the need for government interventions to provide renewable energy sources to maximize the potential environmental benefits [2, 13, 14, 22, 23] of EVs since the level of environmental benefits are highly dependent on the main source of electricity used as fuel for the EVs.

Authors in [12] state that adopting these EVs in regions in which the energy matrix relies primarily on coal or oil could have worse environmental effects than internal combustion vehicles (ICV). Therefore, the development of policies to incentivize electric vehicles' adoption requires further analysis of the impacts. In that sense, reference [23] states that the decisions should be based on the sustainability assessment of the EV's entire life, from the raw material's extraction to its disposal.

When evaluating the life cycle of a vehicle (cradle-to-grate), [1] realized that lithium batteries production (the most used in EVs) accounts for 13% of the energy consumption and 20% of GHG related to the vehicle [1]. Besides, the increase in the lithium use for batteries would lead to its depletion if no recycling program of lithium battery is established. From the social point of view, this paper's systematic review shows that cobalt as raw material for producing batteries might cause a political crisis in the countries that export it [as in 24].

Section 4 will present how the papers about electric vehicles in sustainable supply chains are dealing with the environmental, social and economic concerns in their studies.

3 Methodological Procedures

To perform the review proposed in this paper, at first, we performed a generic search related to sustainable supply chain. We have not included any keyword related to electric vehicles since we decided to gather all the papers published about the subject and select our frame of analysis. By doing this, we reduced the error associated with the elimination of papers that could be related to the theme but does not use a specific keyword as its indexation terms.

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In the approach adopted, we could select those papers that had any keyword related to electromobility among all the papers published. We believed that it was the widest procedure to review precisely the papers published in the selected database. Therefore, the parameters of the search are listed in Table 1. Web of Sciences (WoS) repository was chosen due to its satisfactory coverage, being used in papers with similar methodology as [25]. We highlight that the papers published in 2020 were not considered since it is the current year.

Table 1: WoS database search description

Criteria	Description
Topic	TS = (“supply chain*” OR “supply network”) AND (“sustainab*”)
Database	Web of Science
Refinement	All areas of WoS until 2019.
Search	20/03/2020 at 16:20 GMT-3

Among the papers gathered, the only keywords related to electric vehicles or electromobility was: “electric vehicles”, “battery electric trucks” and “electrification of mobility”. Therefore, a systematic review of the papers indexed with at least one of these keywords was performed.

4 Results and Discussion

Performing the search described in Table 1, it was found 9.558 about sustainable supply chain. Thus, we identified 11,333 keywords related to those publications, highlighting: Sustainability (1118 records), Supply Chain (467), Supply Chain Management (382), Life cycle assessment (LCA) (276), Sustainable Supply Chain (SSC) (253), Sustainable Development (243), Sustainable supply chain management (158), Green Supply Chain Management (156), Circular Economy (CE) (127) and Closed-Loop Supply Chain (CLSC) (126). Note that none of them are directly indicating any kind of electromobility.

As mentioned in the previous section, only three words directly related to electromobility were found: “electric vehicles” (with 22 records), “battery electric trucks” (1 paper) and “electrification of mobility” (1 paper). It suggests that the studies about sustainable supply chain published in the WoS database do not focus on electric vehicles, since only 24 papers among 9.558 study this subject.

We performed a literature review of these papers and the main findings are presented in the following subsections. We provided a brief contextualization of the articles and the analysis was divided according to the study object, emphasizing if they adopt (or not) sustainability indicators. Therefore, Section 4.1 analysis the papers that have the battery as the main object of study, Section 4.2 evaluates those that are focused on the supply chain design and Section 4.3 presents the articles that compare the performance of EVs e ICEVs.

Although papers [24] and [21] are listed among the papers found in the search, they are out of this search scope and, therefore, will not present in the tables. In [24], authors explore how the decision to exclude the use of Congolese cobalt in supply chains

interferes in the political stability and corruption in the Democratic Republic of Congo. Reference [21] focuses on policy strategies for the insertion of renewable energy sources in households in the north of the United Kingdom, considering the use of solar panels and electric vehicles.

Besides, article [13] is not in the tables since it performs a literature review of lithium's supply chain dedicated to producing batteries for EV, identifying safety problems and the suppliers' risks.

4.1 Battery as study object

Only 5 of the 22 articles are dedicated to studying EV batteries (as presented in Table 2). There is a more significant concern with battery disposal [17, 23], since the cathode material is harmful to the environment and human health [23]. Besides, it is responsible for 20% of the GHG emission, when considering EVs' life cycle [1]. Nevertheless, [8] is dedicated to the evaluation of the EVs' charges.

Reference [20] proposes a battery management model in which EVs' users would be registered in a monitoring system. Instead of recharging their batteries, the users would go to a service point and exchange their discharged batteries for a charged one. The optimization model finds the shortest route to the service point. The authors also analyze the savings that this method would bring compared to fuel vehicles, about 37.4% of the expenses.

In [17] a model to compare two kinds of batteries' sustainable performance is proposed: nickel-manganese-cobalt (Li-NMC) and iron-phosphate (LiFeP) batteries. The results do not point to an explicit recommendation of which battery technology is the best, but have important insights: for example, Li-NMC batteries emit less GHG, while LiFeP batteries have more benefits in relation to natural resource depletion).

[23] studies reverse logistics, especially the recycling process of EVs' batteries. The authors analyze some scenarios (with penalties and/or governmental incentives) to evaluate how it would impact the manufacturers' behavior regarding batteries' correct disposal.

With a slightly different perspective, [26] aims to identify the risks to the electricity grid's operation and reliability that arise from the integration of transport and energy supply chains in the Netherlands. The results show that in densely populated areas, such as the city of Amsterdam, the additional demand for energy (from EVs) might exceed the capacity of the local network in the short term, due to the rapid adoption of EVs and old distribution network.

4.2 Supply chain management as study object

Among the 22 articles analyzed, eight are focused on supply chain management, as presented in Table 2. It is observed that although the EVs' market has not achieved its production peak, there are studies concerned with the long-term risks of raw material supplies [1, 17, 23], mainly for batteries that must be replaced before their charging potential drops to 20% (approximately after eight years of use) [1 – 23].

Among the supply chains studied, one of the papers is focused in the usage of biomass for generating bioelectricity [27] and others is dedicated to evaluating the risk

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of disruption in the supply of the minerals used in the EV and ICEV production (as copper, nickel, zinc) [28, 29]. Reference [30] also, analyze the risks of raw material supply in the supply chain of EVs but include the forward flows (e.g., recycling).

Authors in [14] study the design of the automotive supply chain (including EV and ICEV), with emphasis to long term planning to attend the 2030 Agenda considering the EV insertion in the fleet and [31] evaluates how governmental incentives might encourage the supply and the demand of EVs [31].

One of the articles studies the possibility of inserting EVs in a food supply chain, investigating if the local farmers are willing to use EVs to deliver the cargo to local producers [32].

A model to maximize profit related to the lithium batteries' remanufacture used in the EVs is proposed in [1]. The model deals with a closed-loop supply chain considering the quality levels of lithium-ion batteries in the decision to recycle it or not. Using the proposed model, a 30.93% increase in profit can be achieved if the remanufacturing infrastructure is integrated into the lithium-ion battery manufacturing network.

4.3 Papers that compare the performance of EVs and ICEVs

Table 2 shows that three papers compare the performance between the types of EV: Battery Electric Vehicles (BEV), Hybrid Electric Vehicles (HEV), Plug-In Hybrid Electric Vehicles (PHEV) and ICEVs, especially in relation to GHG emission/reduction and cost analysis.

Authors in [12] make a comparative analysis of the three pillars of sustainability in relation to the use of BEV, PHV, HEV with ICEV. By introducing 10% of EVs in the fleet (individually), they found that: the BEVs have a higher potential for reducing the Global Warming Potential (GWP), achieving 12% while the HEVs and PHVs have 4% and 8%, respectively. On the other hand, the water consumption would increase by 1.3 times due to the withdrawal of water for electricity generation, which is higher than ICEVs.

[33] shows that all kinds of EVs would reduce CO₂ emissions compared to ICEV (by petrol and diesel), but only if renewable energy sources were used to generate electricity for the EVs. Although HEVs do not have zero emission, this type of vehicle has a higher energy efficiency level.

There is also one reference that studies the adoption of EVs in a taxi fleet in New York [34]. The findings show that adopting EVs only for fuel savings is not feasible due to the limited capacity of EVs' batteries under assessment. There would be questions related to recharge times and routes. The New York pilot project showed that the taxi driver would achieve a 10% reduction in his income because he had to refuse some trips when the battery level was low [34].

Table 2: Main features of the analyzed papers regarding the role of electric vehicle in a sustainable approach

Study object	Paper	Objective	Environmental	Social	Economic
Battery	[8]	Compare the energy consumption and GHG of four types of EVs chargers throughout the life cycle and assess the environmental impacts of future EV infrastructure.	Energy consumption; GHG; GWP; Cumulative energy demand (CED)	None	None
	[20]	Design an intelligent battery information management system (IBIS) for effective EV battery management.	*	None	Fuel price compared to changing batteries
	[17]	Develop a procedure to analyze the sustainability performance of an EV, with emphases in comparing two types of lithium-ion batteries: Li-NMC and LiFeP.	GHG; Depletion of natural resources	Social risks along supply chain (child and forced labor)	Raw materials supply; Life cycle costs (LCC) for consumer; external costs for society
	[23]	Investigate the socioeconomic and environmental impacts of recycling EV batteries under reward-penalty mechanisms.	Recycling of materials; Environmental Benefit	Social welfare	Governmental incentives
Supply chain	[26]	Identify and analyze the risks to the operation of the electricity grid due to the insertion of electric vehicles in the transmission network.	*	None	Risk of failure and reliability in the supply of the network
	[1]	Propose a model to maximize the profit of battery remanufacturing, considering the quality levels of lithium batteries.	Depletion of natural resources; Recycling of materials	None	Profit
	[27]	Propose a model to optimize the economic and environmental performance of a supply chain.	GHG	None	Global net present value (NPV)
	[14]	Address the long-term dynamics in the supply chain, along with the development of powertrain fleets by 2030.	Equivalent carbon dioxide emission	Unemployment number	Costs of supply chain
	[28]	Develop a MRIO-based life cycle assessment approach to estimate the material footprint of each vehicle alternative considering regional and global supply chains.	Material footprint	None	None

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	[32]	Explore the intention of entrepreneurs operating in the food supply chain to introduce EVs to deliver their products aiming at achieving sustainability.	*	None	None	None
Supply chain	[31]	Analyze the effects of government subsidies on a supply chain, considering an EV manufacturer and consumer.	None	Social welfare	Social welfare	Demand impacts
	[30]	Identify the risk factors of the EV supply chain and help related companies prevent risks.	Environmental risks ¹	None	None	Technical risk ² and market risk ³
	[29]	Propose model to quantify the product supply risk considering the Life Cycle Sustainable Assessment framework (the case study focus on EV and ICEVs).	Impacts of Life Cycle Analysis (LCA)	Supply chain resilience, socioeconomic and geopolitical risk	Own indicator: economic importance (EI)	
EVs and ICEs	[12]	Evaluate and compare the impacts of electric and gasoline vehicles in the environmental, social and economic dimensions.	GWP; Particulate Matter Formation; Photochemical Ozone Formation; Land use	Human Health; Total Tax; Compensation; Employment	Operating Surplus; Gross Domestic Product (GDP); LCC	
	[33]	Analyze the environmental benefits of EVs in relation to ICEVs; identify how the emission savings depend on the source of electricity and the efficiency of the plant.	CO ₂ emission; Depletion of natural resources	None	Comparison with current and future EVs and ICEVs costs	
	[34]	Study the impact of adopting an EV fleet for taxicabs and the factors that might influence this adoption.	*	None	Comparison of EVs and ICEVs costs	
	[22]	Present a study on the effectiveness of government subsidies for EV consumers and manufacturers, finding the ideal subsidy to maximize social welfare.	None	Social welfare	Social welfare	Demand impacts
	[35]	Assess the performance of EV to support EV manufacturers and customers in their decision of produce or buy it, respectively.	*	None	None	Operational characteristics of the vehicle (as price, battery)
	[36]	Examine the impacts of governmental incentive schemes in EV adoption and in the consumer's buying behavior.	None	Social welfare	Social welfare	Demand impacts

Note: (1) Risks of force majeure, air pollution, insufficient funds and change of government subsidy; (2) Node information sharing, product launch cycle and battery manufacturing risk; (3) Parts quality, inventory and product supply delay risk.

Besides, four papers in Table 2 compare the performance of different types of EVs. Among them, we highlight the [35]. Based on experts' opinions (representatives of manufacturers, customers, researchers and academics), [35] raised a list of 22 criteria of performance for EVs. Besides, they performed an analysis of Pareto to identify the nine most significant criteria: price, battery capacity, torque, charging time, overall weight, seating capacity, driving range, top speed and acceleration. These criteria were used to feed the model proposed in FAHP-EVAMIX and evaluate the performance of 12 types of EVs available in the market.

4.4 Governmental subsidies

Due to the initial stage of EVs' insertion in the market, many gaps still need to be filled, such as low autonomy, high purchase price, long charging time and insufficient charging infrastructure [12 - 22]. Therefore, [22], [31] and [36] analyze the impact of a subsidy scheme on EVs' demand and production.

[22] analyzes the effectiveness of the government subsidy for manufacturers to migrate from ICEVs to EVs. The results show that an increase in government subsidies would not always increase the EVs production, since the cost of EV production is still higher than conventional vehicles. Consumer acceptance depends directly on the purchase price, available infrastructure, battery disposal and the need to change it. In contrast, when the subsidy is higher than a pre-defined limit, it becomes profitable for the manufacturer to enter the EV market, although EV production results in a decrease in the profits of ICEVs.

To address these obstacles, countries like China have implemented several subsidies policies, credit taxes and infrastructure improvements to motivate consumers and new manufacturers to adopt/invest in this technology [22]. Similarly, [16] and [22] show that, since 2010, USA has offered a tax credit of \$2,500 to \$7,500 as an incentive to purchase PHEVs and BEVs. Besides, [36] present a discount scheme adopted in Romania and Spain (MOVELE plans): the governments offer a 25% discount rate on EV's purchase price. The UK government has also implemented a similar discount scheme since January 2011.

[37] show that the USA federal, state and local governments have implemented, since 2000, a broad set of incentives to encourage consumer adoption of hybrid vehicle technologies, including credits and income tax deductions as well as exemption of state sales tax, registration fees, emissions testing, excise duties and parking [37].

It is important to highlight that although the mentioned papers showed that the government subsidies had attracted an increasing number of manufactures, there are still doubts about the impact of these subsidies in the demand. So, [22, 31, 36] performed scenarios analysis to evaluate the governmental subsidies' impact on the demand.

As seen in Table 2, papers [22], [31] and [36] deal with the same "sustainability" indicators, investigating the impacts of governmental subsidies in social welfare and in demand and production of EV. However, none of them evaluates the environmental dimension.

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4.5 Sustainability analysis

Among the papers analyzed, only five papers evaluate and quantify at least one indicator of each sustainable pillars (economic, social and environmental). Concerning the environmental indicator, some papers of Table 2 are marked with "**", because they made only a theoretical investigation, highlighting the possible benefits of using EVs to the environment and people.

From the 11 papers that quantify the environmental aspect, the indicators used the most are: GHG and/or CO₂ emissions, raw material depletion, recycling of materials. From the eight papers that quantify the social aspect, the indicator evaluated the most is social welfare.

Regarding the economic indicator, the indicators used the most in the 17 papers that deal with this dimension are: Impacts on demand, costs comparing ICEVs with EVs and risks of failure in supply chains.

At the end, we emphasize that many countries have encouraged the use of EVs, setting goals for carbon reduction and the use of renewable energy sources [21], implementing incentives as subsidy and price discounts [22, 31, 36]. However, most of the papers investigated are dedicated to analyzing the environmental and economic impacts related to the EV insertion in the transport sector. Besides, even if EVs are claimed as a sustainable alternative, hardly ever the studies consider the three sustainability pillars [8].

5 Final considerations

Given the growing concerns about the environment and the scarcity of natural resources, many studies have pointed to EVs as an eco-friendly solution. These papers show that some countries in Europe have proposed government subsidies to attract more manufacturers and consumers to this market, as the MOVELE Spanish plan.

Nevertheless, this paper showed that there is a gap when investigating the role of electric vehicles in sustainable supply chain. Only 22 among almost 9,000 papers published at the WoS database about sustainable supply chain deals with some aspect of electromobility (battery, vehicles and so on). It must be emphasize that: (i) transport is one of the main logistic activities that play an essential role whole in the supply chain [25]; (ii) there is increasing pressure for sustainable process and activities since Agenda 2030 established goals and targets for achieving a sustainable living [38]; (iii) electric mobility is recognized as an important public policy aiming at reducing environmental impacts of transport sectors, as can be seen in [1, 12, 20, 27, 22].

Besides, this research also showed that although some studies claim to be about EVs in the context of sustainability, some of them do not analyze the three pillars of sustainability. Many of them are focused on the environmental aspects, studying material footprint, material depletion, life cycle and battery exchange management projects.

In addition, the literature review arises that there are still doubts about the potential effects of inserting EVs in the transport sector, as there is no past data from purely

electrified vehicle fleets, but there are strong environmental advantages compared to conventional vehicles.

As a limitation, the results found in this paper are limited by the methodological procedures adopted, specifically the keywords and the database. Besides, it is focused on the role of the electric vehicles in the supply chain, but a broader search must be interesting to evaluate the electromobility role from other standpoints.

As suggestions, future studies might try to evaluate the electric vehicles' role in the low carbon economy, approaching different kinds of vehicles and technologies, the optimal location of recharge stations, the management and planning of the transport sector and so on.

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