ADVANCEMENTS IN URBAN FREIGHT TRANSPORT: A COMPREHENSIVE LITERATURE REVIEW ON ELECTRIC VEHICLES

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ABSTRACT

This paper aims to analyze the behavior of electric vehicles in urban last-mile freight transportation and identify the main trends for the upcoming years. The methodology employed in this study is a systematic review with a bibliometric approach, using the Web of Science database. The main finding reveals that the topic of electric vehicles is of great interest and significance in Europe, the United States, and the BRICS countries (Brazil, Russia, India and China - except South Africa), which have been promoting the use of vehicles with low or zero CO2 emissions. This finding emphasizes the need to explore these concepts further in order to pursue sustainable actions.

Keywords: Freight transport, Last mile, Vehicle electric.

RESUMEN

Este trabajo tiene como objetivo analizar el comportamiento de los vehículos eléctricos en el transporte urbano de mercancías de última milla e identificar las principales tendencias para los próximos años. La metodología empleada en este estudio es una revisión sistemática con un enfoque bibliométrico, utilizando la base de datos Web of Science. El principal hallazgo revela que el tema de los vehículos eléctricos es de gran interés y relevancia en Europa, Estados Unidos y los países BRICS (Brasil, Rusia, India y China - excepto Sudáfrica), que han estado promoviendo el uso de vehículos con bajas o nulas emisiones de CO2. Esta constatación subraya la necesidad de profundizar en estos conceptos para llevar a cabo acciones sostenibles.

Palabras clave: Transporte de mercancías, Última milla, Vehículo eléctrico.

1. INTRODUCTION

Environmental changes and accelerated technological progress are central aspects of the contemporary global economic scenario (De Assis et al., 2022c). New technologies can increase production efficiency and reduce resource consumption, and this dynamic is particularly relevant for the automotive sector, as it is one of the sectors that invests the most in research and development, but also contributes a significant portion to greenhouse gas emissions - GHG (Santos et al., 2021; De Assis et al., 2022b; De Abreu et al., 2022).

Companies from various sectors are trying to find environmentally sustainable solutions to minimize environmental impacts caused by their activities, therefore, currently, diesel commercial vehicle manufacturers around the world are on a technological journey to replace diesel with other energy sources, especially by electricity (De Assis et al., 2022a). The industry's focus was given to electric mobility, seen today as the most suitable solutions to mainly eliminate carbon dioxide (CO2) and carbon monoxide (CO) emissions (De Abreu et al., 2023). Even with all the efforts made by the automobile industry, there is still a lot of work to be done, especially for what is proposed in terms of electromobility (Da Costa et al., 2022).

In order to carry out the decarbonization process in the transport sector, one of the main measures to be considered is the adoption of electric vehicles (MCKINNON, ALLEN AND WOODBURN, 2011), where the light vehicle segment is considered the initial path for the process (IEA, 2020; WELCH, 2020). The implementation of electric trucks, intended for urban freight transport, is a reality in Brazil as well as in the world, and such a transformation is justified by the transport sector being responsible for more than 50% of the total consumption of diesel oil (IEA, 2016), and particularly the urban transport sector having a share of 18% in oil consumption, followed by road passenger transport (IEA, 2017).

Although it seems distant, the year 2050 is very close, even when one thinks of the estimated period for the road transport of freight and passengers to meet the global goal of the Paris Agreement to reach zero emissions, and one of those responsible for the emission of pollutants is the transport sector, motivated by the burning of diesel, the main fuel used by commercial vehicles. The use of vehicles with zero emission of pollutants to replace diesel-powered vehicles can help to achieve the established target.

The main objective of this review paper is to search and analyze articles published on the web of science platform, which bring the behavior of the electric vehicle theme in urban freight transport in the last mile, and its proposal is to explore possible gaps in the themes related to the theme, and the way they are addressed. For this, in the following section a bibliometric analysis is presented, then the systemic analysis of the articles, after the results and discussions and finally the conclusion.

2. MATERIALS AND METHODS

In order to obtain state-of-the-art information on freight transport with electric vehicles in the last mile, a systematic review with a bibliometric approach was developed to identify and analyze

relevant studies on the subject. As a result, the steps described below were adopted. In Step 1, the most relevant keywords for the efficient development of the research were defined, as well as the definition of inclusion criteria, as explained in Table 1. It should be mentioned that the use of combinations between keywords directly linked to electric vehicles and last mile were considered relevant, and their choice was defined through a brainstorming process. Subsequently, the authors refined these words to provide more consistency in the study.

Table 1. Description of Search Strategies

CRITERION	**DESCRIPTION**
Database	Web of Science
Topics	*TS = ('Freight Transport' AND 'Last Mile' AND 'Electric Vehicle*') OR TS = ('Trucks' AND 'Last Mile' AND 'Electric Vehicle*')*
Search Method	Direct Search
Inclusion	(I) Time of coverage: (2018-2022); and (II) Source Relevance
Qualification	(I) Does the study address road freight transport with electric vehicles? (II) Does the study deal with the last mile? (III) Does the research present a well-founded literature review? and (IV) Are the Conclusions and Results consistent with the objectives?
Search Date	September 27, 2022

In Step 2, a direct search was carried out in the Web of Science database. We consider all your data/index sources. In addition, documentary research was carried out in important information bases of institutions and scientific initiatives that deal with the last mile and electric vehicles. Thus, the initial database consisted of 168 studies. Then a temporal filter was performed, considering articles from 2018 until 2023, where 137 studies remained. Step 3 presents data processing, which consists of consolidating and organizing the data for the preparation of technical information for the analysis of the use of electric vehicles in the last mile. Finally, Step 4 presents the development of the research report, here expressed in the form of an article, containing the knowledge produced from the research analyses.

3. BIBLIOMETRIC ANALYSIS

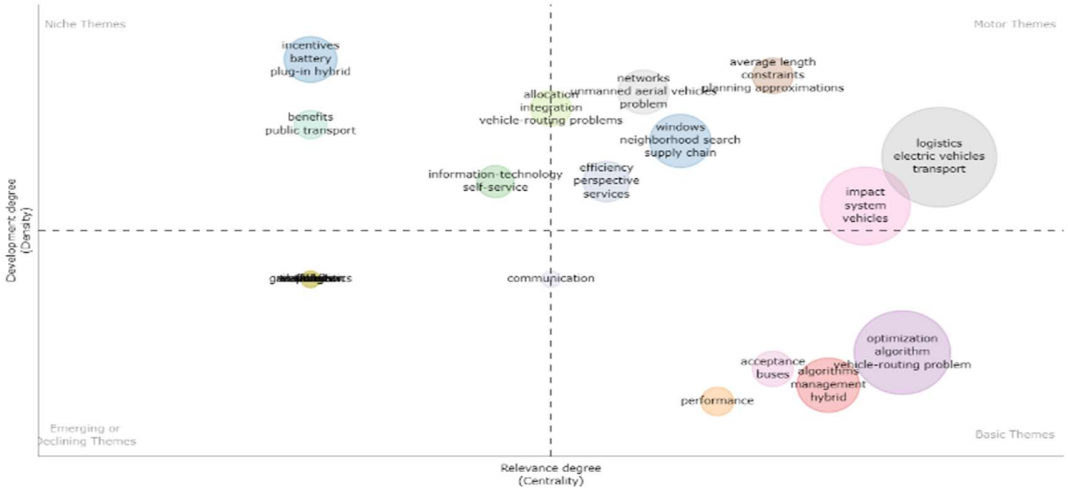
Su and Lee (2010) point to bibliometric analysis as a technique for analyzing the behavior of publications in a quantitative manner. The technique allows the visualization of data on the progress of the subject in a given time frame and possible gaps in research, potential forms of approach and journals for publication. Thus, to achieve the objective of this study, a combination of bibliometric and systemic research on the subject of study was carried out. RStudio® was used as an aid to organize the data of the papers found. Figure 1 visually showcases the most prominent keywords derived from the analyzed papers, providing valuable insights into the field of last mile operations. Notably, it highlights the prevalence of terms directly linked to the last mile, such as delivery, e-commerce, and cargo cycles. Furthermore, the figure accentuates the importance of keywords related to performance, acceptance, cost, and optimization, underscoring their significance in evaluating and optimizing last mile processes. These findings shed light on key

areas of focus and can inform strategies aimed at enhancing last mile operations efficiency and effectiveness.

Figure 1: Keywords cloud in the initial scope.

Furthermore, using RStudio®, it was observed that approximately 17% of studies specifically addressed the logistics aspect, indicating the relevance of the chosen keywords in the initial search. The thematic map depicted in Figure 2 highlights clusters of keywords that are particularly significant in minimizing the environmental impact of road transportation, enhancing its performance and efficiency through various practices. These practices include the integration of information technologies, utilization of route optimization algorithms, and enhanced sector management. The emergence of these keyword clusters reflects a growing interest in mitigating environmental concerns and improving the overall sustainability of urban freight transport.

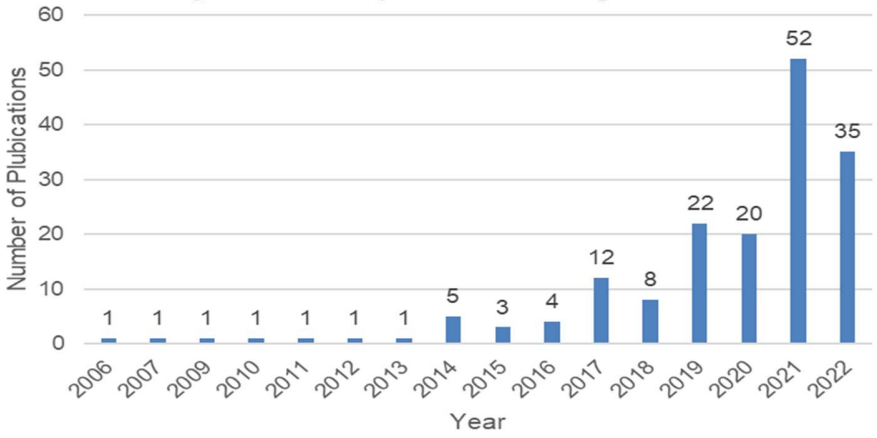
Figure 2: Thematic map of the initial scope.



It was noted first, for this initial scope, the timeliness of publications, being 2006 the year of the first work entitled "Study on interoperability unit for an automobile network" by Jung, Yang and Baek (2006). After this finding, the increase in publications was concentrated between 2017 and 2022, with 2021 being the year with the highest number of publications, proving that the discussion

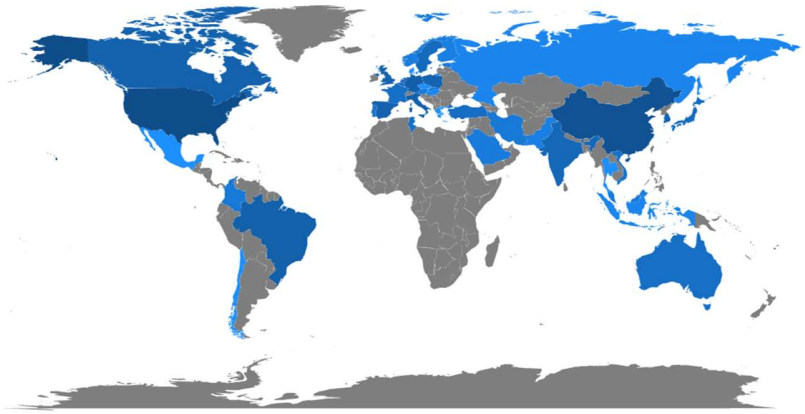
is relevant to the present day. Figure 3 shows in the graph the relationship between the number of publications over the years.

Figure 3: Quantity of Publications per Year.



In the geographical scope, it was noted that the scientific production around the world is well distributed, being null in the continent of Africa, part of South America, and North America. This result can be explained by several reasons, such as being developing countries, having delicate commercial and political relations, or predominance by another mode of transportation among other issues. Figure 4 illustrates this distribution.

Figure 4: intensity map of scientific publications distribution by country.



After the formation of the initial scope, filters were conducted for articles with alignment to the theme.From this new base, a database was organized for the organization and classification of the journals according to the Journal Citation Reports (JCR). The journals that stood out with JCR greater than 7.0, in this scope, are shown in Table 1.

Table 2: Indication of Journals by their Impact Factor.

Source Title	Number of Publications	Impact Factor	ISSN/e-ISSN
ENVIRONMENTAL SCIENCE & TECHNOLOGY	2	11.357	0013-936X
JOURNAL OF CLEANER PRODUCTION	1	11.072	0959-6526
JOURNAL OF RETAILING AND CONSUMER SERVICES	1	10.972	0969-6989
SUSTAINABLE CITIES AND SOCIETY	3	10.696	2210-6707
TRANSPORTATION RESEARCH PART E-LOGISTICS AND TRANSPORTATION REVIEW	2	10.047	1366-5545
IEEE TRANSACTIONS ON INTELLIGENT TRANSPORTATION SYSTEMS	2	9.551	1524-9050
JOURNAL OF ENERGY STORAGE	1	8.907	2352-152X
TRANSPORTATION RESEARCH PART B-METHODOLOGICAL	1	7.632	0191-2615
JOURNAL OF INDUSTRIAL ECOLOGY	1	7.202	1088-1980
COMPUTERS & INDUSTRIAL ENGINEERING	1	7.180	0360-8352
TRANSPORTATION RESEARCH PART D-TRANSPORT AND ENVIRONMENT	6	7.041	1361-9209

The results show that 36.84% of the sample of 57 articles have JCR greater than 7. They also indicate the adherence to the theme for the journal "Transportation Research Part D-Transport And Environment" with 6 publications, being the second largest journal in the scope with publications. Overall, it can confirm the relevance of the topic nowadays, given the increase in the number of publications over the years. The year 2021 presented almost 31% of the publications of the initial scope before the applied filters, proving the previous statement. The journals with adherence to the research theme are shown in the table in this section and indicate relevant journals for publications.

4. SYSTEMIC ANALYSIS OF THE PUBLICATIONS

As a complement to the bibliometric analysis, an attempt was made to understand the content of the most relevant studies in the database through a systematic review. This review allows us to identify relevant information in these studies and possible gaps for future work on the subject, as shown in Table 3.

The studies analyzed in Table 3 share the central objective of improving sustainability in last-mile deliveries, but they approach this issue in different ways. A common feature is the concern with greenhouse gas (GHG) emissions and energy efficiency. The methodology used varies from optimization modeling to statistical analysis and data collection through structured questionnaires. The results of the studies emphasize the importance of electric vehicles in reducing operating costs and emissions, especially in last-mile deliveries. Automation, including the use of delivery robots, is seen as a promising strategy for improving efficiency and reducing environmental impacts. In addition, the choice of retail channel, such as "clicks and bricks", is identified as a critical variable affecting GHG emissions in deliveries of fast-moving consumer goods.

It is also worth noting which studies address specific aspects related to last-mile delivery. Al-Dal & Celebi (2021), for example, focus on the efficiency of electric vehicles, while Li et al (2021) explore automation in distribution. Pahwa & Jaller (2022) investigate e-commerce strategies, Zhou et al (2020) analyze psychological factors and Garus et al (2022) evaluate sustainability in a real case study context. The studies are globally relevant, as efficiency and sustainability in last-mile deliveries are common challenges faced by logistics companies around the world. They provide valuable insights into how to make informed decisions to reduce costs and environmental impacts, while meeting customer demands.

Table 3: Comprehensive overview of the key findings derived from the studies incorporated within the database.

Reference	Type of Approach	Objectives	Main Contribution Points	Gaps
Al-Dal & Celebi (2021)	Application / Mathematical Model	The paper outlining an integrated model for optimizing routing and fleet composition decisions in urban freight distribution using electric vehicles. They aimed to minimize operational costs by optimizing delivery routes for various combinations of electric and conventional vehicles. This involved using the results to determine the most cost-effective fleet composition, considering factors like maintenance cost, fuel expenses, and emissions.	The results show that battery electric freight vehicles are cost competitive with conventional diesel vehicles, particularly for smaller (Class 3) light commercial vehicles. The study identified financial incentives were sufficient to offset additional purchase and fuel expenses, leading to lower total costs of ownership.	The study mostly concentrated in assessing conditions in California.
Li et al (2021)	Application / Mathematical Model	The research assesses the GHG emissions throughout the life cycle of automated suburban ground delivery systems, which consist of a vehicle for the last mile and a robot for the final 50 feet. The evaluation includes both small and large internal combustion engine vans (ICEV) with capacities of 125 and 350 cubic feet (V125 and V350), as well as battery electric powertrains (BEV). These vehicles were examined across three delivery scenarios: (i) traditional, with a human-driven vehicle and human delivery; (ii) partially automated, with a human-driven vehicle and robot delivery; and (iii) fully automated, involving connected and automated vehicles (CAV) with robot delivery.	The results indicate that the robot's contribution to GHG emissions over the life cycle is insignificant, at between 2% and 6%. Compared to the conventional scenario, full automation results in similar GHG emissions for the V350-ICEV, but around 10% higher for the V125-BEV. Notably, conventional delivery with a V125-BEV has the lowest GHG emissions, totaling 167 g CO2e per package, while partially automated delivery with a V350-ICEV generates the highest emissions, reaching 486 g CO2e per package.	The study didn't consider optimal delivery performance across the ground and airborne systems based on package size, numbers of deliveries, customer density, vehicle fuel economy, weather restrictions, traffic restrictions, and contactless delivery demand.
Pahwa & Jaller (2022)		The study discusses the opportunities and challenges associated with different last mile strategies for e-commerce delivery. As such, it sought to develop a framework for last mile distribution using Continuous Approximation (CA) techniques to establish: ● The performance of different last mile distribution strategies in various	The study emphasized the competitiveness of electric trucks over diesel trucks and explored the advantages of utilizing environmentally friendly vehicles like freight bikes. It also discussed the pros and cons of outsourcing last-	Test with more types of e-commerce.

Reference	Type of Approach	Objectives	Main Contribution Points	Gaps
	Mathematical Model	delivery environments; ● The key factors for the economic and environmental viability of a distribution strategy; and ● The appropriate market conditions for implementing a given distribution strategy.	mile delivery to crowdsourcing fleets or customers. The authors suggested employing smaller, eco-friendly vehicles located near markets for faster, cost-efficient, and environmentally friendly deliveries. In conclusion, the analysis supported the adoption of electric trucks for last-mile delivery due to their emissions reduction and cost advantages compared to diesel trucks.	
Zhou et al (2020)	Questionnarie Application / Mathematical Model	The study aims to empirically examine how psychological factors impact the behavioral intention of online consumers to adopt a technology. To achieve this, an extended Unified Acceptance and Use of Technology model was formulated, and data from 525 structured questionnaires were gathered for analysis.	The results show that performance expectancy, effort expectancy, social influence and facilitating conditions have positive influences, while perceived risk has a negative impact on behavioral intention. In addition, the difference in behavioral intention between demographic groups was analyzed, which may open up space for the development of innovative strategies to promote the adoption of the self-service last mile parcel delivery service.	Tests for larger instances.
Wang et al (2020)	Literature Review / Application	Propose a novel and efficient parcel delivery mechanism through car trip sharing, to address the mismatched logistics capacity and ever-increasing parcel delivery demand. Different from existing car sharing solutions.	The results of the research shown high potential of electric vehicles and the usefulness of electromobility in last mile deliveries. The business partner of the research is now on the stage of electric freight vehicles implementation into vehicles fleets.	The study considers only one market segment, in this case, the postal service.

Reference	Type of Approach	Objectives	Main Contribution Points	Gaps
Garus et al (2022)	Literature Review/ Mathematical Model	The paper presents the results of a sustainability assessment conducted in a real-world case study of a last-mile delivery service. The methodology used combines multi-criteria decision-making analysis, sustainability principles, and scenario analysis to address the conflicting needs of stakeholders in the last-mile delivery system. The study applies this framework to the European Commission's Joint Research Centre delivery system and compares six alternative solutions, including different vehicle types and automated delivery options.	The findings indicate that making modest investments in delivery droids can result in substantial operational cost savings and enhance the environmental sustainability of the system. However, it's important to note potential social sustainability challenges related to safety and fairness. Investment in delivery droids could lead to significant savings on operational costs and a new way to improve the environmental performance of the system.	Sustainability in safety and equity.
Akeb et al (2018)	Mathematical Model/ Roteirization	The study investigates how to use the power of crowd logistics, focusing on making deliveries by a network of neighbors in the event of home delivery failure by the carrier (when the customer is not at home). Using the platform, the carrier delivers the package to the nearest neighbor who will guarantee the final delivery. For this, the authors intend to demonstrate a method of calculating the number of neighbors needed and their geographical position in order to collect and complete deliveries.	The results indicate that the model studied offers a basis for last-mile delivery services to establish a network of neighbors. This allows carriers to deal with customer absence by delivering the package to a member of the network and avoiding additional deliveries and costs in dense urban areas. In addition, from an environmental point of view, this approach to crowd logistics is ecologically advantageous, as it makes efficient use of available resources and reduces the need for operators to travel, resulting in lower emissions and less traffic.	Studies on the issue of operating costs of conventional and electric vehicles and battery life.
Jaller et al (2021)		The study analyzes the total costs of ownership and environmental impacts over the life cycle of last-mile deliveries in vehicles with different	The findings indicate that parcel deliveries involve short trips (95% under 160 kilometers), numerous	Omits inventory and operating costs, and does

Reference	Type of Approach	Objectives	Main Contribution Points	Gaps
	Mathematical Model	powertrains and fuels, taking into account incentives in California. It examines driving patterns in various delivery areas, such as beverages, warehouses, parcels, groceries and food, based on actual truck trip data. Statistical analyses are carried out to compare these patterns between different areas, vehicle classes and powertrains, as well as between fleets of parcel transportation companies. In addition, the study estimated the health damage related to pollutant emissions over the life cycle.	stops, and lower driving speeds compared to other delivery types. The total cost of ownership for class 3 to 6 conventional diesel vehicles in last-mile use was estimated at around $282,000 to $305,000, with health-related costs ranging from $38,000 to $64,000 during the vehicle's lifetime. Battery electric freight vehicles were found to be cost-competitive with diesel counterparts, particularly for smaller light commercial vehicles (Class 3). Financial incentives effectively offset additional purchase and fuel expenses, resulting in lower total ownership costs.	not consider crowdsourced drivers.
Shahmohammadi et al (2022)	Mathematical Model	The study created a stochastic model to measure the GHG emissions variability associated with distributing and purchasing fast-moving consumer goods (FMCGs) using three primary retail channels in the UK. The research revealed that opting for "bricks and clicks" (click and collect via physical store delivery) is likely to reduce GHG emissions when replacing traditional purchases. However, FMCGs purchased through dedicated operators with parcel delivery typically result in higher GHG emissions compared to those obtained from traditional retailers.	The results show that the quantity of items purchased and the distance traveled in the final delivery stage are the main factors influencing the variability of GHG emissions in the three retail channels. In addition, replacing delivery vans with electric cargo bikes can result in a significant 26% reduction in GHG emissions in parcel delivery. Finally, differences in GHG emissions are observed in the "last mile" of traditional shopping in the UK compared to three other countries (China, the Netherlands and the United States), mainly due to the different proportions of transport modes used (walking, car, bus and bicycle).	The acceptability by the different actors remains to be evaluated. The maximum distance that the neighbor or customer accepts to travel, the desired gain or the cost of this solution in relation to the cost of a second delivery by the carrier.

Reference	Type of Approach	Objectives	Main Contribution Points	Gaps
Shi et al (2020)	Mathematical Model/ Algorithm	The study sought to develop an algorithm to optimize the Electric Vehicle fleet for delivery services, seeking to reduce social costs (including operating costs and customer waiting time) of service provision mobility. Interestingly, an attempt was made to optimize considering sharing vehicles, which resulted in a gain in service performance.	Developed a reinforcement learning based algorithm to provide ride-hailing services to communities with an EV fleet, developed a scalable off-policy reinforcement learning framework with decentralized learning and centralized decision-making processes.	The unknown customer trip requests and additional complexity of recharge demands make it difficult to develop a model-based optimization algorithm to solve the dynamic.
Iwan et al (2021)	Mathematical Model/ Algorithm	The study aims to evaluate the energy efficiency of electric vans in real-life situations, specifically in the context of mail deliveries, using the Nissan eNV200 for the research. This work fills a significant knowledge gap with both theoretical and practical relevance. Importantly, the experiment took place in real-life conditions, during commercial operations at a renowned global postal services company. This research is part of the international EUFAL project, funded by the Electric Mobility Europe program.	The results of the research highlighted the considerable potential of electric vehicles and their advantageous applicability in last-mile deliveries. The research's commercial partner is currently moving forward with the implementation of electric cargo vehicles in its fleets.	Use of more complex information for greater reality and program specification.

In short, these studies make a significant contribution to understanding and improving last-mile delivery practices. They highlight the importance of considering economic, environmental and social factors when making logistics decisions. The adoption of electric vehicles, automation strategies and choices of appropriate retail channels are some of the approaches suggested to improve efficiency and sustainability in last-mile deliveries.

5. DISCUSSION

It is noticed that the theme is interesting from the perspective of freight transport in the last mile and means gains in reducing greenhouse gas on the planet, a topic of great relevance and discussion in the last decade. It is noted that the theme has made significant gains in recent years in terms of results in reducing pollutant emissions, but when compared to developed countries, it still requires more research related to the sector. The road ahead is still long and it is believed that encouraging companies to use non-electric vehicles is important in the quest to replace vehicles that still use polluting fuels. Furthermore, policymakers and stakeholders must recognize the importance of supporting and incentivizing sustainable practices in the last mile, including the use of non-electric vehicles. This can be achieved through the formulation and implementation of supportive policies, regulations, and incentives that encourage the adoption of eco-friendly technologies and practices. These measures should not only target businesses but also address the challenges faced by individual consumers and their behavioral patterns.

It can be seen that the world population is still not prepared for changes in energy use and lifestyle, because for most of the population, it is really difficult to change the current lifestyle. However, it seems that, little by little, some changes are taking place, mainly in the automobile industry, which has been seeking to develop models of cargo vehicles with low or zero CO2 emissions. By investing in research, fostering collaboration, and implementing supportive policies, the potential gains from sustainable last-mile freight transport can be fully realized. This will contribute to significant reductions in greenhouse gas emissions, improved air quality, and a more sustainable future for our planet.

6. CONCLUSION

In this work, we show that the decarbonization of freight transport has been the object of study in several countries, not restricted to just one continent. The BRICs (with the exception of South Africa) for example have researched on the subject, in addition to European countries and the USA. On the African continent, only one country had an article chosen within the pre-established criteria.

According to the research, some issues still need to be further explored, such as: battery charging, vehicle autonomy, the operating cost of using electric vehicles and the need for tests with e-commerce. Regarding the last mile, a difficulty is the distance between the supplier/distributor and the customer, because according to the results, the autonomy of electric vehicles influences the decision-making for which vehicle should be used. The objective of this work was achieved in

presenting an overview of the theme regarding the approach of electric freight vehicles in the last mile on the world stage, including the BRICS, observing the growth and exploration of this theme in the scope of international publications and in the study of Technologies.

As a suggestion for future work, a study is suggested to identify the increase in production and registrations of electric trucks in a temporal analysis of 20 years, given the incentive of developed countries to acquire zero and low emission vehicles and as a proposal present in the document of agreement between the participating countries of the 26th United Nations Conference on Climate Change (COP-26) held in 2021 in the city of Glasgow - Scotland.

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