

# Mapping Research on Electric Vehicles in Logistics and Transportation. A Bibliometric Analysis

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*Abstract– Due to the growing importance of environmental issues associated to logistics and transportation (L&T) activities, less pollutant vehicles are getting relevance in the execution of distribution tasks. Thus, a huge number of scientific publications related to the usage of electric vehicles in L&T has appeared in recent years. This work consists of a bibliometric analysis on the published articles in the last decade. To do so, we have extracted a database from Scopus to identify keywords, authors, institutions and countries of relevance. In addition, graphical relationships among existing publications have been identified.*

*Keywords– Electric Vehicles, Logistics and Transportation, Bibliometric Analysis.*

## I. INTRODUCTION

Nowadays, transportation is one of the main activities in supply chain management (SCM). Therefore, companies are increasingly looking for new alternatives to optimize their transportation activities, reducing the impact on the environment, costs and, even, increasing profits. Thus, it is evident that today's companies not only seek the sustainability of their activities from an economic perspective, but also consider the social and environmental. These three areas are known as the Triple Bottom Line, which according to Bhinge et al. [1] are important due to the necessity of combining and integrating them with the different productive processes of each company.

Transportation is a critical process in supply chain management not only for its contribution to operational efficiency but also for its environmental impact. For instance, road transportation accounts for approximately 18% of total greenhouse gas emissions in the EU [2]. As a response, one of the main trends in sustainable logistics and transportation (L&T) is the use of electric vehicles to deliver goods from logistic facilities to customers who can be located everywhere.

To understand the growing importance of the usage of different electric vehicles in L&T, this work proposes a bibliometric analysis to study the scientific outcomes related to this trend in SCM. This bibliometric study emphasizes on the identification of the most prominent authors, institutions and countries in terms of number of published manuscripts and their impact (citations). Moreover, we analyse the knowledge areas in which the most important works are published. Additionally, we include a temporary evolution of published works classified by their number of citations. VoS Viewer® software was used to identify relationships such as

co-occurrence of keywords, timeline evolution of co-citation, among others.

The remainder of this document is organized as follows: Section 2 provides an explanation of the methodology used to carry out this study. Section 3 presents the analysis of the information found within the bibliometric study. Finally, Section 4 outlines some conclusions and drawn future research lines derived from this work.

## II. METHODOLOGY

Bibliometrics can be defined as a set of research techniques that analyzes quantitatively the bibliographic material [3], [4]. Bibliometric studies are based on quantitative and reliable data retrieved from scientific databases (e.g., Web of Science, Scopus, Google Scholar, etc.). Thus, a bibliometric analysis is based on a stable foundation of knowledge. This method has been used in management research to improve the understanding of theoretical structures in any scientific domain (e.g., management information systems, operations management, international management, logistics and supply chain management, etc.) [5]. From both academic and practitioners' points of view, it is important that the published material in a specific research field, such as the usage of electric vehicles in L&T tasks, could be classified so that researchers and practitioners can follow all the field's advances and trends [6]. In recent years, the development of analytic tools related to scientific outcomes have generated the increasing number of bibliometric analysis [7]. The bibliometric analysis developed in this work was based on the scientific literature indexed by Scopus database (www.scopus.com) considering that "Scopus uniquely combines a comprehensive, curated abstract and citation database with enriched data and linked scholarly content..." [8]. In addition, Scopus allows us to "quickly find relevant and trusted research, identify experts, and access reliable data, metrics, and analytical tools for confident research strategy decisions." [8].

With the aim of delve deeper into the use of Electric Vehicles in Logistics and Transportation, a bibliometric analysis was carried out. To do so, as a first step we started by retrieving from Scopus database the published works with the words 'electric vehicles' appearing either in the title, abstract or keywords. The initial result provided 105,259 documents.

Therefore, the number of documents was refined by applying the following criteria:

1) We only consider works that have been published in the last decade (i.e., from 2012 to 2021).

2) The type of documents was limited to journal articles.

3) Knowledge areas considered as non-relevant to this work were excluded: e.g., Materials Science; Chemistry; Chemical Engineering; Earth and Planetary Sciences; Biochemistry, Genetics and Molecular Biology; Medicine; Agricultural and Biological Sciences; Pharmacology, Toxicology and Pharmaceutics; Neuroscience; Psychology; Arts and Humanities; Health Professions; Immunology and Microbiology; Nursing; Veterinary; Dentistry.

4) Keywords related to electric vehicles, optimization techniques, operations management were selected: e.g., Electric vehicle, Electric vehicles, optimization, electric vehicles EVs, costs, fuel economy, plug-in hybrid vehicle, efficiency, commerce, greenhouse gases, stochastic systems, transportation, electric vehicle, scheduling, roads and streets, electric vehicle (EV), algorithms, hybrid electric vehicle, genetic algorithms, plug-in electric vehicles, fleet operations, simulation, dynamic programming, decision making, integer programming, forecasting, Particle Swarm Optimization (PSO), multiobjective optimization, uncertainly analysis, computer simulation, numerical model, economics, environmental impact, sensitivity analysis, performance assessment, sustainable development, Monte Carlo method, cost benefit analysis, renewable energies, battery, fuel consumption, Unmanned Aerial Vehicles (UAV), buses, distribution systems, economic and social effects, demand response, greenhouse gas, stochastic models, algorithm, fuzzy logic, and sustainability.

Once the aforementioned refinement process was executed, our search returned 325 documents (as of November 19, 2020), which were used to carry out this mapping of research. Table I summarizes the methodology followed in this study. Information about the most prominent authors in the field in terms of published works and citations, institution and countries were analyzed. Additionally, the resulting database (325 articles) was loaded into VoS Viewer® software in order to provide graphical understanding of the relationships among authors, keywords and related indicators. VoS Viewer was developed by Van Eck and Waltman [9]. Some of the generated figures are:

– Timeline evolution of Co-citation between authors: To generate it, we consider authors with at least one publication on the topic and at least five citations in their corresponding works. Thus, our figure considered a total of 571 authors (out of 941) meeting these conditions.

– Co-occurrence of author keywords: In this graph we considered keywords with at least 10 co-occurrences. As a result, 85 (out of 3206) keywords satisfy the condition. In addition, 12 keywords were eliminated by hand because they were far from the scope of this study: e.g., automobile manufacture, crashworthiness, china, life cycle assessment (lca), article, etc.

– Timeline evolution of keywords: To obtain this graph, we considered the same conditions used for the co-occurrence graph.

TABLE I  
RESEARCH METHODOLOGY

Unit of analysis	Published Journal Articles
Period of analysis	2010 to 2020
Search engine	Scopus
Query string	Due to its length is available at: <a href="http://bit.ly/BibliometryEV">http://bit.ly/BibliometryEV</a>
Number of evaluated articles	325

### III. ANALYSIS

To better understand the body of knowledge related to the usage of electric vehicles in L&T, we have carried out a set of analysis. First of all, we have identified the most prominent authors in terms of published works and their corresponding citations. To do so, authors were ranked by number of published works (TP) and by total citations (TC). In Table II, we can see in the left side the most prolific authors ranked by TP, while in the right side they are ranked by TC. As can be seen, Javier Faulin is the author with more published articles; however, Macharis, C., who is in second place by TP, is the most cited author, accounting for 149 citations. Regarding Faulin's most cited article, "Electric vehicles in logistics and transportation: A survey on emerging environmental, strategic, and operational challenges", it was published in the journal *Energies* and has 62 citations. This article identifies the different research challenges related to EV's in logistics and transport systems, and classifies them in terms of environmental, strategic or operational issues. Regarding Macharis' works, his most cited article is "The hourly life cycle carbon footprint of electricity generation in Belgium, bringing a temporal resolution in life cycle assessment". It was published in *Applied Energy* and has 68 citations. This work deals with the CO2 footprint generated by electricity producers either in the construction or in the generation phases.

TABLE II  
TOP 10 DOCUMENTS AND CITATIONS: AUTHORS

R	Author	TP	TC	Author	TP	TC
1	Faulin, J.	6	141	Macharis, C.	6	149
2	Macharis, C.	6	149	Faulin, J.	6	141
3	Lebeau, P.	5	81	Van Mierlo, J.	5	145
4	Van Mierlo, J.	5	145	Zhang, W.	5	84
5	Zhang, W.	4	84	Kucukvar, M.	4	82
6	Grube, T.	4	62	Lebeau, P.	5	81
7	Kucukvar, M.	4	82	Grube, T.	4	62
8	Laporte, G.	4	48	Robinius, M.	4	62
9	Emde, S.	4	14	Stolten, D.	4	62
10	Gao, C.	4	43	Li, J.	4	59

In terms of institutions, the Rheinisch-Westfälische Technische Hochschule Aachen's is the institution with most published documents, accounting for 11 articles, as can be seen in the left side of Table III. Its most cited article, with a total of 78 citations, "The electric location routing problem with time windows and partial recharging" was published in the European Journal of Operational Research, which is one of the most recognized journals in the field of operations research and management sciences. This article presents a location routing approach considering the routing of electric vehicles and location decisions for charging stations, simultaneously. With respect to the number of citations, Table III-right side, the institution receiving most citations is the Norwegian University. Its most cited article is "Comparative Environmental Life Cycle Assessment of Conventional and Electric Vehicles" [10] by Hawkins, et al. was published in the Journal of Industrial Ecology.

TABLE III  
TOP 10 DOCUMENTS AND CITATIONS: INSTITUTIONS

Ranking	Institution	TP	TC	Institution	TP	TC
1	Rheinisch-Westfälische Technische Hochschule Aachen	11	175	Norwegian University of Science and Technology	1	669
2	Southeast University, Nanjing	9	59	Technische Universität Darmstadt	6	544
3	Tongji University	7	62	University of Kaiserslautern	1	530
4	Technische Universität Darmstadt	6	544	Lufthansa Technik	1	367
5	Politecnico di Torino	6	53	York University	2	266
6	Tsinghua University	6	202	University of Calgary	1	259
7	Vrije Universiteit Brussel	6	149	Tsinghua University	6	202
8	Universidad Pública de Navarra	6	141	Rheinisch-Westfälische Technische Hochschule Aachen	11	175
9	Seoul National University	5	123	University of Brescia	1	153
10	North China Electric Power University	5	24	University of Bergamo	1	153

However, the most cited paper on the topic, with 367 citations, is the article: "The electric vehicle-routing problem with time windows and recharging stations" [11] by Schneider, et al. was published in 2014 in Transportation Science. This article is from the Technische Universität Darmstadt and presents an E-VRPTW problem in which a route is planned by considering the possibility to recharge the vehicle recharges, during the execution of the routes, in the available stations. In addition, capacity and time windows constraints are considered. The problem was solved by means of a hybrid heuristic combining Tabu Search (TS) with the nearest neighbor algorithm. Particularly, the Technische Universität Darmstadt, manage to stand out by being well ranked in both aspects (published works and citations). Being in fourth place in number of published documents (6) and ranked second in terms of citations (544).

Another important aspect to analyze is the geographical origin of the published works on the topic. In table IV, we can see the list of most influencing countries. Similar to the previous tables, the left side is devoted to rank countries by the number of published works while the right side is related to the number of citations. It can be seen that China is the country with the largest number of documents (105 articles) which is about twice the number of works from the United States. Whereas, Germany has the highest number of citations (1117), which represents 128 more citations than China. As for China, its most cited article is "Battery swap station

location-routing problem with capacitated electric vehicles" [12] published in Computers and Operations Research. This article accounts for 129 citations and provides a solution to the problem of battery swap station location and routing of electric vehicles.

TABLE IV  
TOP 10 DOCUMENTS AND CITATIONS: COUNTRIES

Ranking	Country	TP	TC	Country	TP	TC
1	China	105	989	Germany	45	1117
2	United States	50	821	China	105	989
3	Germany	45	1117	United States	50	821
4	Italy	31	459	Norway	8	729
5	United Kingdom	28	266	Canada	19	523
6	Canada	19	523	Italy	31	459
7	Spain	17	203	United Kingdom	28	266
8	South Korea	14	192	Sweden	9	234
9	France	13	151	Australia	8	224
10	Netherlands	9	133	Spain	17	203

As can be seen in table V, it is important to identify the scientific areas in which articles on the topic are published. To understand the taxonomy of the scientific we decided to use the knowledge areas defined by Scopus. Therefore, eleven areas were classified into four different categories. In the first category, are those areas considered as leading, large, several dozen percentages shares; in the first position is Engineering due to the nature of the topic. In the second category, we can find three areas that can be defined as significant, medium several percent share. In the third category, are the less important areas which represent a few percent shares, and finally, the last category, the non-important areas, which represents less than 1% of the total.

TABLE V  
RESEARCH ON ELECTRIC VEHICLES IN LOGISTICS AND TRANSPORTATION ACCORDING TO SPECIFIC DISCIPLINES

Rank	Subject area	Papers	%
1. Leading, large, several dozen percentage share	Engineering	219	27.7%
	Environmental	120	15.2%
	Energy	113	14.3%
	Social Sciences	100	12.6%
2. Significant, medium, several percent share	Computer Science	67	8.5%
	Business, Management and Accounting	60	7.6%
	Mathematics	45	5.7%
3. Less important, small, at most few percent share	Decision Sciences	39	4.9%
	Economics, Econometrics and Finance	21	2.7%
4. Unimportant, minimal	Multidisciplinary	4	0.5%
	Others	3	0.4%

During the first six years of the analyzed period, the number of articles did not exceed thirty-two, showing moderate increases and decreases throughout these years.

However, since 2018 we can testify a sharp rising of published works about Electric Vehicles in Logistics and Transportation. Furthermore, 2020 is the year with more published articles on the topic, accounting for almost 30% of the published papers within the evaluated time period. Regarding citations, even though these papers used to have a huge number of citations, just 2.3% of the total papers have been cited at least 100 times. On the other hand, 16.3% of the published articles have 20 or more citations. It is also important to mention that, even though 2020 was the year with more published papers, it has the lowest rate of citations after 2021 so far. This could be due to the recent publication of such articles. Table VI summarizes the aforementioned information.

TABLE VI  
ANNUAL CITATION

Years	TP	≥100	≥50	≥20	≥10	≥5	≥1	TC
2012	11	1	0	1	4	0	4	197
2013	23	2	2	4	4	3	4	1094
2014	17	1	2	6	3	1	3	777
2015	32	3	4	9	2	7	5	1076
2016	19	0	2	9	2	2	3	455
2017	27	1	4	9	9	2	2	924
2018	43	0	0	7	11	9	14	424
2019	67	0	0	11	14	19	14	651
2020	100	0	0	1	4	12	38	239
2021	11	0	0	0	0	0	1	1
Total	350	8	14	57	53	55	88	5838
%	100%	2,3%	4,0%	16,3%	15,1%	15,7%	25,1%	

Moreover, it is essential to analyze the top cited articles, at the time this research was carried out. The first one was published in the Journal of industrial ecology [10]. This article presents a mixture of information comparing environmental life cycle and electric vehicles. The next paper was published in the Journal of Transportation Science [11]. This paper focuses on electric vehicle routing problems with time windows and recharging stations, which is similar to the topic of the third article referenced in Table VI. In general, most of the articles retrieved from our search focus on routing problems with many variants related to the usage of electric vehicles in distribution tasks.

TABLE VII  
TOP ARTICLES

R	Article	Journal	TC
1	Comparative Environmental Life Cycle Assessment of Conventional and Electric Vehicles	Journal of Industrial Ecology	669
2	The electric vehicle-routing problem with time windows and recharging stations	Transportation Science	367
3	Vehicle Routing Problems for Drone Delivery	IEEE Transactions on Systems	259
4	Routing a mixed fleet of electric and conventional vehicles	European Journal of Operational Research	163
5	A survey on two-echelon routing problems	Computers and Operations Research	153
6	Battery swap station location-routing problem with capacitated electric vehicles	Computers and Operations Research	129
7	A methodology to evaluate the competitiveness of electric delivery trucks	Transportation Research Part E: Logistics and Transportation Review	108
8	The time dimension and lithium resource constraints for electric vehicles	Resources Policy	102
9	Electric vehicle route optimization considering time-of-use electricity price by learnable partheno-genetic algorithm	IEEE Transactions on Smart Grid	95
10	A hybrid simulated annealing algorithm for location and routing scheduling problems with cross-docking in the supply chain	Journal of Manufacturing Systems	87

TABLE VIII  
TOP JOURNALS

Source	SJR	TP	TC	C/D
Journal Of Cleaner Production	1.89	22	355	16,1
Applied Energy	3.61	19	441	23,2
Transportation Research Part D Transport And Environment	1.66	19	266	14,0
Sustainability Switzerland	0.58	17	123	7,2
World Electric Vehicle Journal	0.19	12	22	1,8
European Journal Of Operational Research	2.36	11	355	32,3
Resources Conservation And Recycling	2.22	9	94	10,4
Energies	0.64	7	108	15,4
Energy	2.17	7	59	8,4
Energy Policy	2.17	7	94	13,4
Transportation Research Part E Logistics And Transportation Review	2.3	7	220	31,4
Computers And Operations Research	1.66	5	316	63,2
Transportation Research Part B Methodological	2.9	5	150	30,0

In the following, we will refer to the journals in which the analyzed articles have been published. In Table VIII, we can observe the scientific journals ranked by the number of published works. Table VIII considers 4 aspects: the Scimago Journal Rank score given to the journal in 2019, the number of published papers (TP), the number of citations of the articles belonging to the journals (TC), and the average citation per paper (C/D). It should be noted that the SJR score indicates the visibility and prestige of the journal. Although there is no correlation, it is observed that the European Journal of Operational Research has the second highest number of citations per paper and, at the same time, it is one with the highest SJR scores. However, it is surpassed by Computers and Operations Research, which almost doubles it in the average number of citations per document.

It is worth to mention that the Journal of Cleaner Production is the source with most published works (22), even though its scope is not directly related to electric vehicles or logistics and transportation. Another relevant journal is Applied Energy, which has the highest SJR score among the listed sources and also reports the highest number of citations.

To finish, we have used VoS Viewer software to better represent relationships among the documents returned by our search string. In that sense, an analysis of the authors' keywords was performed by co-occurrence, i.e., the times a keyword appears in different documents. We set a threshold of at least ten appearances for each keyword in order to facilitate the analysis of the most popular topics in research papers (among 3206 keywords, only 73 meet the aforementioned condition). As shown in Figure 1, Keywords are represented by circles, where the bigger ones represent greater frequencies of appearance in the different articles. In addition, four different clusters can be clearly identified according to their colors. The yellow cluster could be identified as "Electric Vehicles" and their associated issues. The green cluster is devoted to logistics and transportation in which topics such as urban transport and trucks are considered. The blue cluster is related to supply chain management, including reverse flows. The red cluster mainly represents environmental concerns.

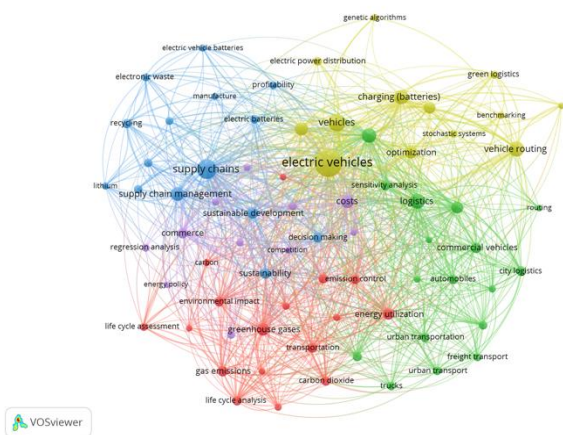


Fig. 1 Co-occurrence of author keywords.  
(High Resolution image available at: <http://bit.ly/Figure1EV>)

Figure 2 shows the timeline evolution of the keywords co-occurrence. It provides an idea of the evolution and trends of the different keywords over the analyzed period of time. Based on the figure, trends from the last year can be highlighted, such as: recycling, electronic waste, profitability, and supply chain management. In 2017, keywords such as the introduction of electric vehicles, carbon emissions and commercial vehicles were relevant in the published works.

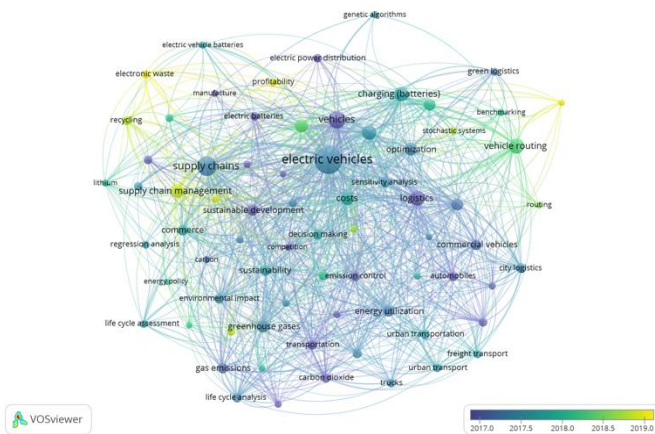


Fig. 2 Timeline evolution of keywords from 2010-2020.  
(High Resolution image available at: <http://bit.ly/Figure2EV>)

Next, an analysis of the Co-Authorship was carried out taking into account the following parameters to generate the graph and facilitate the analysis: A maximum of 20 authors per document, minimum 2 appearances in documents and 5 citations per author. Thus, a total of 126 authors (out of 941) satisfies these conditions. In Figure 3, small groups are evident, showing the collaborations between authors. For example, a strong interaction is seen between Wang, T. and Li, J. Also, this shows the evolution of interactions between authors over the years. For example, Wang, J. and Li, Y. had a

Co-Authorship in 2016 while Zhao, Z. and Li, J. did so in 2020.

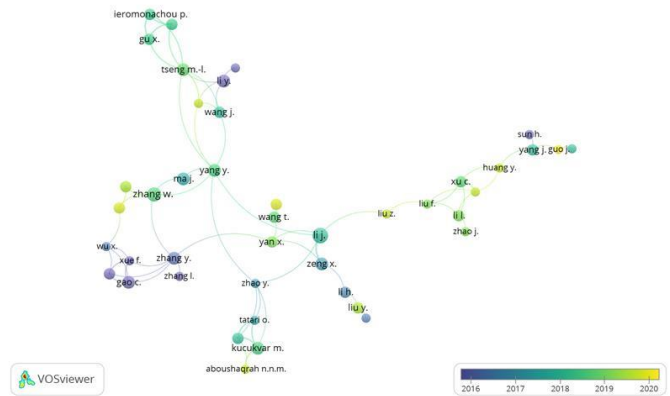


Fig. 3 Timeline evolution of Co-citation between authors from 2010-2020  
(High Resolution image available at: <http://bit.ly/Figure3EV>)

#### IV. CONCLUSIONS AND FUTURE RESEARCH

In this work, a bibliometric analysis was proposed and carried out about the implementation of electric vehicles in the different logistics activities. In order to have a more general view and facilitate the analysis, graphs were made using the VoS Viewer® software showing the most relevant keywords and authors of the subject under study. In addition to the existing relationship, it shows the historical evolution over the years. Additionally, an analysis of the search results denoted the most cited and published authors, institutions, and countries.

Considering the results, in 2017, the introduction of electric vehicles in different activities of the supply chain is evidenced. Its relevance has increased over the years, now a days its implementation relies in reducing the emission of gases, the greenhouse effect and increasing profits. Thus, the areas mainly focused on the transportation with electric vehicles are areas completely related to engineering and environment, as they maintain a very close relationship and a common interest.

With the analysis of the articles, it was established that an electric vehicle is one that produces and uses its own energy through batteries and electric motors, and that brings benefits in environmental terms, decision-making, and optimization of operations. Resulting as a viable and recommended option since it is not only cost efficient for public/private companies, but it also brings social benefits such as reducing pollution in cities. In addition, the country's sustainable business development will boost the economy. However, it is advisable to evaluate the implementation of hybrid vehicles as a preamble for their implementation in logistics activities, due to the limited access to energy charging infrastructures in developing countries.

Within the bibliography there is evidence of the scarcity of models related to the types of chargers and the effects of battery degradation, which is key since the life cycle of each of these can be estimated, highlighting the importance of their study in detail to have a budget of the spare parts necessary for the continuation of commercial operations through the use of electric vehicles. Additionally, the challenges presented by the implementation of EVs become evident. For logistics and transportation, it is important to consider the strategic, operational, and tactical decisions involved in the implementation of these vehicles. To this end, research related to the location of charging stations and the autonomy of the vehicles has already been carried out, but further research is expected.

This research mapping could be used as a basis to research opportunities regarding the usage of electric and constrained distance vehicles in activities related to logistics, transportation, and supply chain management. Also, for future studies, a different search string could be used that focuses on the use of electric vehicles in sectors such as public transport, so that it can be identified if it brings benefits as strong as in the transport of goods. Also study the viability of building sustainable energy charging infrastructures in developing countries.

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