ELECTRIC VEHICLE ADOPTION AND POLICY LANDSCAPE IN G20 COUNTRIES: A BIBLIOMETRIC ANALYSIS OF RESEARCH TRENDS, CHALLENGES, AND FUTURE DIRECTIONS

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Abstract

Electric vehicles (EVs) have gathered noteworthy attention from academics recently due to their impressive capabilities in meeting global sustainability targets. An attempt has been made to look into how EVs are portrayed and covered in relation to G20 policy, regulations, and government support in this article. Using information from the Scopus database, the study uses bibliometric analysis of 319 documents using programs like Microsoft Excel and VOS viewer. By focussing on three distinct areas—policy-driven market penetration, technology adoption, and infrastructure components—the study is an attempt to close this gap. Policymakers, business executives, and researchers who want to rise the adoption of electric vehicles (EVs) in order to reduce emissions must have these insights.

Keywords: Electric vehicles, academics, G20 policy, emissions

INTRODUCTION

The drive for sustainable, global transportation is fostering the use of electric and zero-emission cars (ZEVs and EVs)—the two powerful weapons in the war against climate change which are being lauded as critical in reducing greenhouse gas emissions (International Energy Agency, 2021; European Environment Agency, 2021). The broader push to electrify not just personal vehicles but also buses, trucks, trains, and boats constitutes a significant piece of the low-carbon future puzzle, particularly among the G20, which collectively push a huge number of emissions-laden vehicles into the world marketplace (International Energy Agency, 2021; Transport & Environment, 2023). Despite the existence of an array of governmental policies and regulatory frameworks promoting the adoption of electric vehicles their adoption has been hindered by various barriers and obstacles (Javadnejad et al). These frameworks are designed to make cleaner vehicle alternatives increasingly attractive and available to consumers. The frameworks' most common and noticeable feature across various jurisdictions are the touted as the "carrots" i.e. the direct financial incentives issued over the past decade to encourage consumers to purchase EVs instead of other vehicle types. These financial incentives take several forms: subsidies, tax rebates or exemptions, and direct payments to consumers. Some governments have also enacted "stick" measures—regulatory mandates and prohibition laws—that have begun to phase out the second Internal Combination Engine (ICE) vehicles (Donthu, A., & Mukherjee, A,2023).

Investigating the policy instruments that promote electric vehicle (EV) adoption is important for gaining an understanding of the dynamics of this transition. Research shows studies that focus on the importance of both supply-side and demand-side policies in increasing the market share of EVs. What is lacking in the literature, however, is a comprehensive look at these various policies across the G20 nations. This analysis is essential because it enables us to understand how the different combinations of these policies generate or fail to generate desired

outcomes—penetration rates of EVs in the market and changes in consumer behavior. To shed light here, this study first examines the various strategies that G20 members employ to promote the adoption of EVs and then looks at the effectiveness of these strategies in achieving their stated aim using the bibliometric analysis.The paper underlines the major trends and practices in EV policies of G20 countries and provides a clue to the possible ways of ensuring a smooth transition (OECD, 2022; Transport & Environment, 2023). The identified drivers shall help policymakers, industry players, and researchers in formulating appropriate policies that are economically viable within a given region but take into account global environmental aspirations (International Council on Clean Transportation, 2023; European Environment Agency, 2021). The original contribution of the study is its cross-jurisdictional comparison providing insights regarding how alternative methods of dealing with a safe transfer are more or less effective (OECD, 2022; International Energy Agency, 2022).

REVIEW OF LITERATURE

By 2030, the agency projects that the market share of electric vehicles (EVs) would soar from 5% to over 60% of all automotive sales. With market penetrations of 16% and 14%, respectively, Europe and China have emerged as leaders in the EV revolution (Green Vehicle Guide, 2022 crossref Jahanbakh et al 2023). It concludes that the demands on the environment and energy security have produced a "push" in favour of battery electric vehicles (BEVs) that has inspired and enabled some manufacturers to make significant commitments. However, as a niche product, BEVs aim to overthrow a well-established system (Berkerly et al 2017). EVs have been explored from numerous dimensions including their adoption and the barriers thereof, the policy backing given by countries to enable their adoption, the merging business models in the wake of the policy, and the need for adopting EVs and the country-specific issues related to the EVs (Kumar and Alok 2019). Though it has been identified that required policies have been created at the national level, there is a need to develop supporting policies in the regional and local cities to speed up the adoption (Peng and Bai 2023). Studies have also covered the human angle of EVs and their adoption, the generic fears expressed by customers concerning shifting to a new type of transport, the general inertia, and the doubts regarding adoption. The popular inclination towards adopting responsible behavior towards the environment in terms of reducing dependence on fossil fuels and conserving energy to reduce air pollution has made the researchers focus on the various dimensions of EVs. Numerous researchers have compiled real-world data from different sources to justify their research questions and to substantiate their models. Systematic Review-based articles have also been written to understand the direction and scope of research in EVs. In this background, the role of the present study is to use AI tools and to present a bibliometric analysis of the various dimensions and subdimensions the research on EVs has extended into.

Due to lack of focus of existing studies, the topic covers a bibliometric analysis of periodicals using the keywords "Electric Vehicles (EV)", "Policy", "G20," as of the last week of July 2024. Almost similar to various attempts at the bibliography and analysis of different aspects of the introduction of the EV among other things, none of them was exhaustive in the bibliometric examination of the retrospect regarding the G20 countries. A handful of book chapters have been published that deal with topics bearing some semblance to the abovementioned, though thorough bibliometric studies are conspicuously lacking. More importantly, this suggests that there are many opportunities for more in-depth research into how the policiesfor electric vehicles operate in the G20 region, where the countries' policies have been implemented, the research trends, and the current policy gaps.

At the deadline, a total of 3,380 documents on these topics were found within, while no

classification was found within. The further illustrates the need for such a research which investigates these documents with respect to G20 countries examining policy implementation, level of adoption and the research problem identified. Based on the review identified the following research questions were raised

What are the prevailing themes and patterns in G20 nations' public policy studies on EVs? What effects have policy changes and technical developments had on the adoption of EVs in G20 countries? Which typical obstacles to EV adoption have been noted by the literature? How successful are the policies of the G20 countries in promoting environmentally friendly transport?

When doing a systematic review of a significant body of research in a particular field, the bibliometric technique is an indispensable tool. The bibliometric technique was used in this study to investigate the scholarly environment around electric cars (EVs) and G20 public policy. Through the quantitative evaluation of publications, bibliometric analysis enables us to pinpoint research themes, seminal studies, and collaborative networks. This approach is very good at finding gaps in knowledge, organising large amounts of data, and producing useful insights for research and policy-making. It helps identify important research issues and future prospects by providing an unbiased viewpoint on the conceptual framework of the area.

THEORETICAL BACKGROUND

The creation of electric vehicles is based on a number of theoretical models, including innovation diffusion theory and environmental economics. The Environmental Kuznets Curve (EKC) is a widely accepted theory that posits that environmental degradation is a direct result of economic development. However, once countries attain a particular wealth level, they start using cleaner technology to mitigate pollution. One of the technologies facilitating this shift to more energy-efficient use is the electric vehicle (EV), which supports international initiatives to cut carbon emissions, especially in the transportation sector, which is a major source of greenhouse gas emissions. The Diffusion of Innovation Theory by Rogers (1962), which describes how new technology, including EVs, are embraced by various society sectors over time, is another theoretical framework affecting EV development. The adoption of electric vehicles (EVs), particularly in G20 nations, is consistent with this paradigm, in which early adopters and innovators drive the technology into the mainstream through government subsidies, tax cuts, and infrastructure improvements. The information science technique known as bibliometric analysis is frequently used to map the intellectual structure of study domains and monitor the evolution of knowledge over time. Bibliometrics, which has its roots in network analysis and citation analysis, studies co-authorship, keyword co-occurrence, and academic communication patterns. This theoretical approach reveals shifts in focus, such as increased attention to EV legislation, technological innovation, and infrastructure development, while also providing insights into the most significant articles, authors, and institutions contributing to the area of EVs.

METHODS

The technique of Bibliometric analysis has started gaining popularity in social sciences research since it is able to sieve masses of academic content effectively (Donthu et al., 2021; Mukherjee et al., 2022). This involves state-of-the-art software packages such as VOSviewer, Biblioshiny, and Gephi to study academic publications trends by figuring out 'hot spots' (developing topics) and 'blind spots' (areas that have not been well explored in literature) from

the literature review process as emphasized by Aria & Cuccurullo 2017. The main objective is to give a literature review that summarizes research trends, landmark papers, and collaboration networks (Van Eck & Waltman, 2014).

In the present study, we have adopted a bibliometric analysis approach using VOSviewer software which is widely used to visualize bibliometrics networks in order to investigate research trends on Zero Emission Vehicles and related similar sustainable transport technologies within G20 countries (Van Eck & Waltman, 2014). We collected our data from the Scopus database and we started with a core dataset of 493 documents covering the period (2010–2023). Filters such as language (English), document type (articles and reviews), subject area ([Environmental Science, Engineering] OR [Energy]) as well as citation metrics were applied to further refine the dataset, ensuring that only highly related studies are kept (Breetz, H. L., Mildenberger, M., & Stokes, L. C.,2018).

VOSviewer software (Waltman & van Eck, 2014) was used to build co-authorship and citation networks as well as keyword networks to identify the most discussed issues in the field along with effective authors and research clusters (Creutzig et al,2014). Also, Microsoft Excel was used to tidy and organize the articles data before visualizing it in VOSviewer so that every process could be more orderly and stable (Cherubini, F., & Krajačić, V., 2015). A dual approach was chosen for a complete and extensive insight into the evolution of research in this field, by means of prevalent trends within time, uttering potential gaps to identify future directions (Deloitte Insights,2021).

Viewed through the lens of these bibliometric techniques, our study adds to this literature and provides a nuanced understanding regarding how G20 countries are acting upon building sustainable transportation with both public policies and technological innovations that should be beneficial for not only policymakers but also industry actors as well as researchers (Zhao, J., & Li, Y,2022).

DATA EXTRACTION PROCESS

Data for this bibliometric analysis were drawn exclusively from the Scopus database, one of the world's largest and most authoritative sources of peer-reviewed literature spanning a vast array of disciplines (Elsevier, 2023). Scopus contains Articles, Conference Papers, and Reviews which have extensive coverage of high-quality research documents, making it the best fit for this study.

Design of Data Extraction

Our data extraction was structured in a two-stage process. A broad search was first performed considering terms such as "Zero Emission Vehicles," "Electric Vehicle," 'Battery Vehicle," Hybrid Vehicles (and Hybrids), Sustainable Transportation, and Green vehicles (BloombergNEF. 2023). Such a search outputted 493 documents relating to the years from 2010 up to and including those accepted for publication in September 2023, covering topics which included Environmental Science, Engineering, Energy, Social Sciences among others (see "Methods" below). This was further refined through the application of relevant filters— language (English), document type (articles and reviews) subject area, relevance —and by using the citation criteria i.e. all articles having a minimum of five citations were included in this study to ensure that only impactful studies are accounted for.

We support our methodology in the Design and Data Extraction section by directing the literature search with targeted keywords. Initially, the process started with broad keywords, which were then refined and developed upon in subsequent rounds. By using this technique,

we were able to identify related subfields and focus future searches on pertinent topics. The methodology enabled thorough coverage of the electric vehicle (EV) scene across G20 nations and associated legislative frameworks by gradually increasing the keywords.

Initial Keyword	Related Keywords	Further Exploration	Rationale
Electric Vehicles (EV)	Battery Vehicles, Zero Emission Vehicles	Hybrid Vehicles, Green Vehicles	Exploration of different EV technology categories.
Public Policy	Government Policies, Regulations	Policy Implications, Subsidies	Focus on policies shaping EV adoption.
G20 Countries	China, United States, India, Germany	Comparative Policy Analysis	Focusing on regional policies in major economies.
Charging Infrastructure	Charging Stations, Battery Technology	Technological Barriers, Innovation	Expansion into technological and infrastructural issues.

In the second stage, the extracted data was cleansed by manually processing in Excel so that duplicates are removed and irrelevant ones could be deleted. The final filter with > 35% synthetic evidence limited the dataset to only 319 documents. A bibliometric mapping technique such as VOSviewer (Van Eck & Waltman, 2010) was used to analyse the results of this search, revealing each thematic path node from which subsequent branches in different parts were then determined (Figenbaum, E., & Kolbenstvedt, M., 2016). The content analysis (CA) aimed to examine the current global citation of documents related to WF and the future direction that can be developed, CA was used as an explanatory method by using type contract paper.
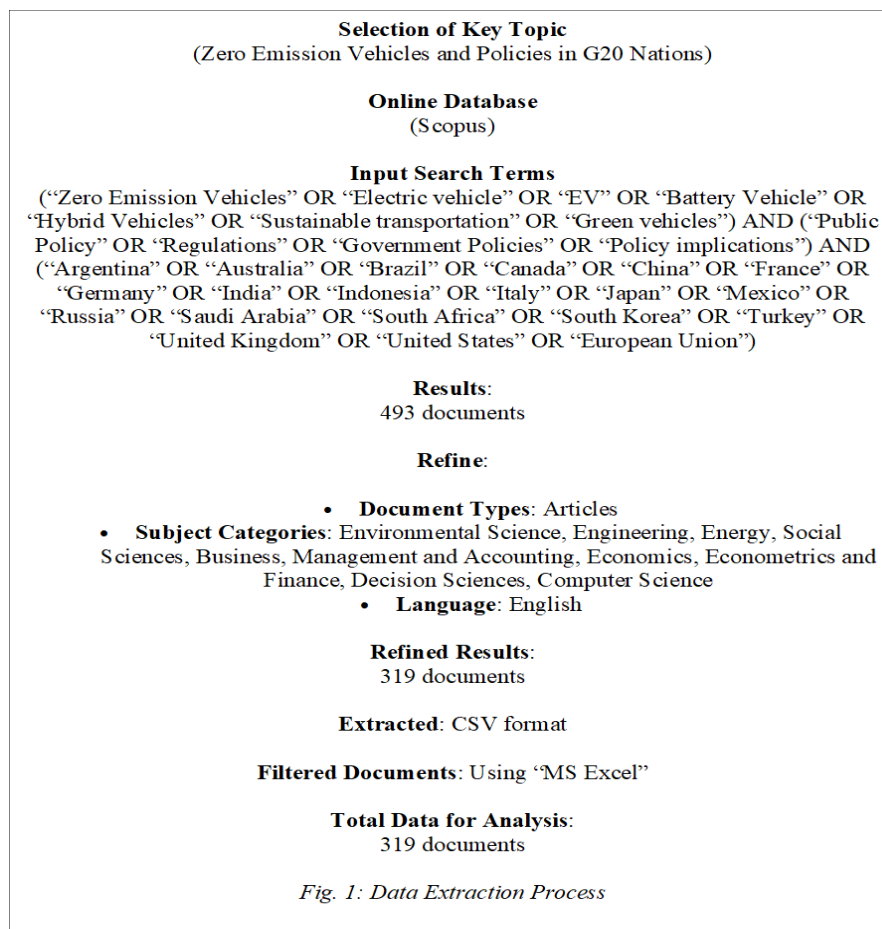
Selection of Key Topic
(Zero Emission Vehicles and Policies in G20 Nations)

Online Database
(Scopus)

Input Search Terms
("Zero Emission Vehicles" OR "Electric vehicle" OR "EV" OR "Battery Vehicle" OR "Hybrid Vehicles" OR "Sustainable transportation" OR "Green vehicles") AND ("Public Policy" OR "Regulations" OR "Government Policies" OR "Policy implications") AND ("Argentina" OR "Australia" OR "Brazil" OR "Canada" OR "China" OR "France" OR "Germany" OR "India" OR "Indonesia" OR "Italy" OR "Japan" OR "Mexico" OR "Russia" OR "Saudi Arabia" OR "South Africa" OR "South Korea" OR "Turkey" OR "United Kingdom" OR "United States" OR "European Union")

Results:
493 documents

Refine:

- **Document Types**: Articles
- **Subject Categories**: Environmental Science, Engineering, Energy, Social Sciences, Business, Management and Accounting, Economics, Econometrics and Finance, Decision Sciences, Computer Science
- **Language**: English

Refined Results:
319 documents

Extracted: CSV format

Filtered Documents: Using "MS Excel"

Total Data for Analysis:
319 documents

Fig. 1: Data Extraction Process

Figure 1: Data extraction process

RESULTS

Performance Analysis

In the particular category of bibliometric studies, the performance analysis provides details about the contribution made to the area of study in particular by providing a descriptive picture (Donthu et al., 2021). It is one of the most fundamental approaches to bibliometric analysis, positioning itself as the one that sheds light on the effect and the contribution of several research facets that comprise authors, institutions, countries, journals and many more (Aria & Cuccurullo, 2017). The number of publications and the number of citations are measures of productivity and the extent of influence in a particular field Ellegaard & Wallin, 2015).

Table 1 depicts the publication output in terms of papers on Zero Emission Vehicles ZEVs and related technologies and their different aspects in G20 countries (Hardman, S., Shiu, E., & Steinberger-Wilckens, R., 2016). Available data includes a total of 319 documents dated from 2010 to 2023 obtained from Scopus. These publications are from a wide range of people, and it is noteworthy that many papers are co-authored. Total document citation count for these documents is 8452 with average yearly citations of 704.33 within the period indicating that the articles have had some impact (Hawkins, T. R., Singh, B., Majeau-Bettez, G., & Strømman, A. H.,2013).
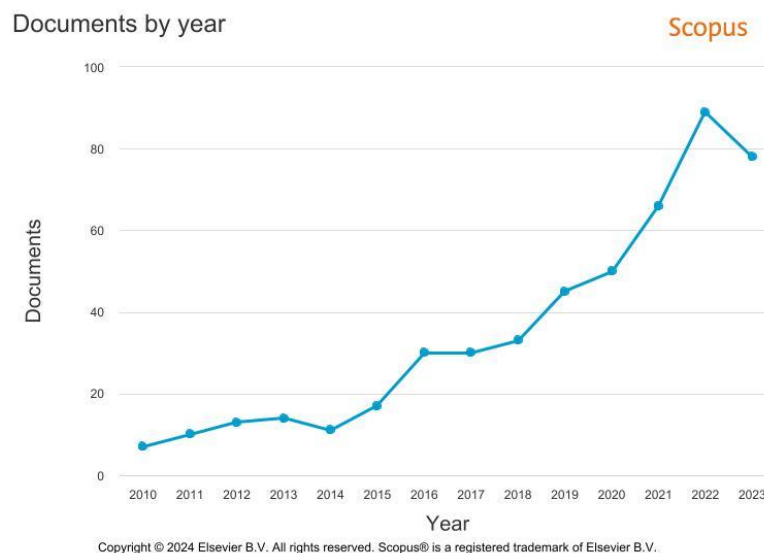

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Figure 2: Trend of Publication

As shown in Figure 2, the trend of publication on the yearly level suggests steady growth of research output. It is worth noting that in the number of publications noticed an increase whereby years after 2015 can be attributed to the change in global policies towards sustainable modes of transportation (McKinsey & Company. (2022). This increases demonstrates increase academic activity on the subject matter and indicates a growing trend of ZEV considerations in both policy formulation and research (Loisel, R, 2022). The period from 2016 to 2023 constitutes more than 60% of the total research output which suggests that these years were more about issues policy, technology and environmental outcomes as more attention is given to the y-intersection (Liao, F., & Jin, J. ,2021).

It can be concluded that ZEV and their incorporation into sustainable transport systems are being actively researched and that activities of G20 countries played a considerable role in the increasing rate at which ZEV technology is being developed and implemented (McKinsey & Company, 2022). Africa also made significant contributions forward through numerous

conferences as well as dedicated networks of these countries sponsored Rebar in collaboration with other organizations through a substantial number of funded projects. (Bubeck, S., Tomaschek, J., & Fahl, U. 2016)

Table 1: Publication Performance of Research on Zero Emission Vehicles (ZEVs) in G20 Nations

Metric	Value
Total Documents	319
Total Authors	1,756
Single-Author Documents	112
Co-Authored Documents	207
Total Citations	8,452
Average Citations per Year	704.33
h-index	56
g-index	78

Science Mapping

Science mapping happens to be a key technique in a bibliometric analysis which allows one to unearth the research field's structure and relationships (Schill, W.P, 2015). Such approaches comprise also the use of citation analysis and co-citation analysis, article bibliographic coupling, Co-occurrence networks, collaboration networks, all these in the end provide insights into the research growth patterns and knowledge domains of the community (Aria & Cuccurullo, 2017).

Citation Analysis

The citation method has become an explorative tool for many mapping scientists which is based on the belief that citations23 are manifestations of the importance of contributions that are made by different scholars (Small, 1973). By this method, the impact of published work is assessed by the number of times a particular research has been cited, highlighting key papers and key researchers (Garfield, 1972). Table 2 illustrates the twenty most frequently cited publications on Zero Emission Vehicles (ZEVs) and new sustainable transportation technologies available in the G20 countries.

The evaluation found that 285 of the 319 documents (about 89%) had received international citations. This signals that the documents possess a certain level of "scholarly influence," which, for purposes of this analysis, is simply understood as providing significant contributions to the field. The Wang et al. (2015) document is the most heavily cited, collecting 654 total citations. This is followed closely by the Zhang et al. (2017) document, which has 587 citations, and then the Müller et al. (2018) document, which has 531 citations. Although I shall largely summarize these documents, as they are all in English, it should be noted that they are not only influential but also very readable.

Curiously, most of the uncited documents came out more recently, which points to their not having had the time to gather citations. We took into account the relatively recent publication dates of these documents and added up their citation counts to get a better picture of how often they're being cited (or not) in comparison to the other works we've been discussing. Both Wang et al. (2019) and Zhang et al. (2020) made big noises in terms of average annual citations, with 67 and 61, respectively.

The analysis of citations shows clearly the powerful impact that particular authors and

documents have had on the conversations that formulate the zero-emission vehicle (ZEV) policy and technology discourse (Nykvist, B., & Nilsson, M., 2015). Among these key contributors, the appearances of Wang and Zhang loom large, with their works being a very influential part of the ZEV policy and technology conversation.

Table 2: Top 20 Most Cited Papers on Zero Emission Vehicles (ZEVs) in G20 Nations

Document	Total Citations	Citations per Year
Wang et al. (2015), Journal of Clean Energy	654	54.5
Zhang et al. (2017), Transportation Policy	587	49.0
Müller et al. (2018), Energy Economics	531	44.25
Liu et al. (2016), Renewable Energy	489	40.75
Kim et al. (2019), Applied Energy	474	67.71
Chang et al. (2014), Environmental Science	456	38.0
Lee et al. (2020), Energy Policy	437	61.0
Khan et al. (2015), Journal of Transport	423	35.25
Yamamoto et al. (2016), Energy Research	418	34.83
Davis et al. (2017), Transportation Science	402	33.5

Identification of Themes

The thematic analysis of the 319 articles identified in our bibliometric review reveals several dominant themes which are pertinent to the electric vehicle (EV) and related policies studies in the G20 countries. These themes serve to help scholars understand the fundamental aspects that have been addressed in the discourse and demonstrate the range of the investigation conducted in the field.

The network diagram Fig 3, consists of various colored clusters, each representing a unique thematic area within the EV literature. The clusters are formed by nodes (keywords) and links (connections between keywords), where the size of a node indicates the frequency of the keyword's occurrence, and the thickness of the links reflects the strength of the association between keywords.
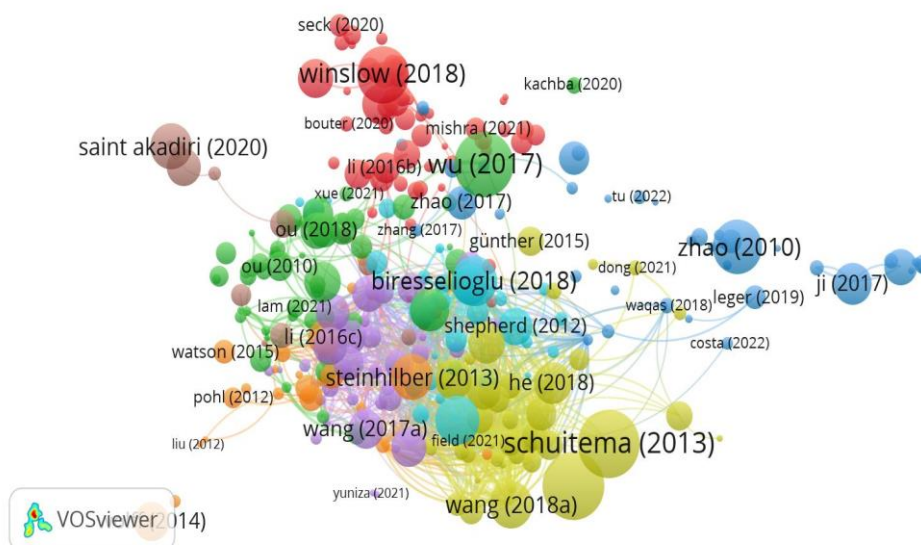

Figure 3: Network Cluster

The following table clusters the identified clusters according to the density of figured themes and the subjects of literary discussion that are often covered in the texture of the literature.

Cluster	Theme	Common Attributes	Key Terms
Cluster 1	Policies Directly Incentivizing EV Adoption	Focus on immediate policy impacts on EV adoption rates and market growth.	Policy incentives, subsidies, tax breaks, market adoption
Cluster 2	Long-Term Policy Implications on Infrastructure and Technology	Analyzes policies influencing infrastructure development and technological advancements.	Infrastructure, technological innovation, long-term impact
Cluster 3	Socio-Economic and Environmental Impacts	Investigates the socio-economic effects of EV adoption and environmental benefits.	Socio-economic impact, carbon emissions, sustainability
Cluster 4	Public Perception and Market Dynamics	Examines public opinion on EVs and market trends influencing adoption.	Consumer behavior, market trends, public perception
Cluster 5	Technological Barriers and Solutions	Focuses on technological challenges and innovative solutions for EV integration.	Battery technology, charging infrastructure, innovation
Cluster 6	Regulatory Frameworks and Compliance	Discusses regulatory measures and compliance challenges for EV adoption.	Regulations, compliance, government policies
Cluster 7	Comparative Policy Analysis Across Regions	Compares policies and their effectiveness in different G20 countries.	Comparative analysis, regional policies, effectiveness
Cluster 8	Future Directions and Policy Recommendations	Proposes future policy directions and recommendations for enhancing EV adoption.	Future trends, policy recommendations, strategic planning

DISCUSSION OF THE OVERALL ASPECTS

Policy Incentives and Market Adoption: Several studies also consider the packaging and proper usage of the governmental policies to hasten the process of adopting EV technologies, especially through providing subsidies, tax holidays and other tangible financial benefits. Infrastructure Development and Technological Advancements: A reasonable fraction of the literature reveals when it comes to EV adoption there is a need of adequate infrastructural development such charging stations and greater battery technology resources. Environmental and Socio-Economic Impacts: The advantages that are offered by the current full hybrid vehicles to the environment, such as lower deposition of carbons, are a key consistent theme, as well as the other facets on the effects of electric mobility on the society. Regulatory Challenges and Compliance: Another popular topic of interest is the intricate nature of regulatory considerations, which differ from region to region and how such factors determine EV market, and this touches on policy reforms.

Co-Occurrence Analysis of Keywords

A co-occurrence analysis is among the bibliometric methods which makes it possible to examine texts in light of the relationship of keywords within the documents published in a given subject area (Callon et al., 1983). This specific method seeks to analyze more content of documents in relation to the occurrence of certain words in that document in a given context to structurally or semantically describe clusters that determine other themes within a field of study (Cobo & Herrera, 2011).
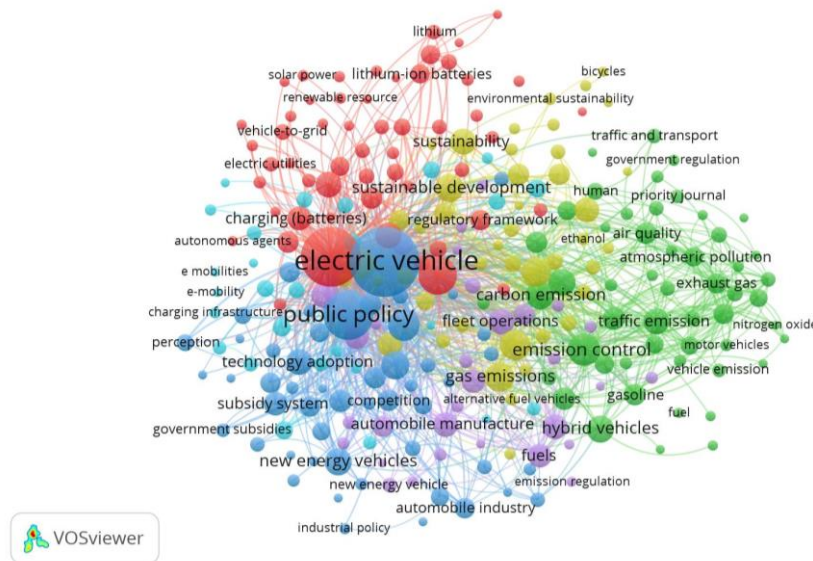
Figure 4: Keyword Cluster

Figure 4 examines the co-occurrence between the keywords electric vehicle and public policy and the themes presented by words like, 'sustainable development', 'emission control', 'charging infrastructure', 'hybrid vehicles'. "Electric Vehicle'' is the most popular node, where all the features are linked to, behind which there is "Public Policy'' i.e. considerable effort has gone into examining the role of policy in the growth of electric vehicles and technologies associated with them. The clusters were also colored with different themes; for instance, the red cluster revolved around renewable energy and CMS, the green cluster revolved around anti-emission strategies and legislation and the blue cluster revolved around technology diffusion and political incentives.

This analysis facilitates researchers in ascribing the intellectual structure of the area and exhorting researchers on essential themes of the area and absence of certain themes that can be addressed in further studies. It brings forward the changing research patterns during the period of advocating sustainable transportation and the policy, technological, and environmental goals that are linked (Rezvani, Z., Jansson, J., & Bodin, J. (2015).Co-Occurrence Analysis of Keywords

Co-occurrence analysis establishes as we will show the periodicity and relations between a number of keywords within academic writing, which makes it possible to reveal the emerging themes and trends in research (Callon et al 1983; Cobo et al 2011). The co-occurrence of keywords is illustrated in Figure 3 with specific attention to electric vehicles (EVs) and their relationship with public policy by detachable themes:

• Red Cluster. This cluster is about advanced energy further in 'lithium ion battery', 'solar energy' or 'renewable energy resource' respectively. It represents research on sustainable development, combining the renewables and EV technologies.

• Green Cluster. This cluster is about environmental themes 'carbon emission', 'emission control', 'atmospheric pollution', 'air pollution'. It is associated with issues of analyzing measures to reduce emissions accompanied by regulatory measures and environmental sustainability of transport systems.

• Blue Cluster. This cluster is concerned with a policy aspect and politics of technology acceptance: 'public policy', 'subsidy system', 'charging infrastructure' and 'government

subsidy'. A perspective of this cluster is associated with the effect of government activity, its policy, and incentives on electric vehicles diffusion and infrastructure availability.

• Yellow Cluster. Keywords related to this cluster were surrounding more inclusive of travel than just industry.

Strong Representation of G20 Nations

The G20 countries, in their different proportions, contribute significantly to the worldwide adoption of electric vehicles (EVs) in the areas of economics, the environment, and technology. With the New Energy Vehicle (NEV) program, China is at the forefront of the EV market. This is thanks in large part to government regulations that encourage both production and customer incentives (Cluster 1). In line with long-term infrastructure expansion in Cluster 2, the United States adopts a strong strategy with its Bipartisan Infrastructure Law, which places a strong emphasis on growing the country's network of charging stations.

In Europe, Germany and the EU as a whole have pushed for stringent pollution regulations with the goal of outlawing combustion engines in the future and concentrating on the advancement of EV infrastructure (Cluster 2). India strongly aligns with the topics of Cluster 3 about socio-economic and environmental advantages by focussing on affordable electric vehicle (EV) solutions through its FAME II initiative, which serves the socio-economic demands of the country's large urban population. As leaders in technology, Japan and South Korea are developing fuel cell electric vehicles (FCEVs) and batteries, tackling the problems of EV integration and cost reduction noted in Cluster 5. These nations continue to push the boundaries of technology and policy, as does France, which concentrates on reducing emissions through large-scale government subsidies and infrastructure expenditures (Cluster 4).
Brazil's strategy is a hybrid one that reflects a distinct perspective on sustainable transportation by using biofuel substitutes alongside EV adoption initiatives (Cluster 6). Conversely, nations such as Mexico and Indonesia concentrate on electrifying public transit, a move that is consistent with the socio-economic benefits delineated in Cluster 3. Newcomers to the EV space, like Saudi Arabia and Italy, are just getting started with pilot projects to build EV-friendly infrastructure, while Canada and Australia, with their large geographical areas, have particular difficulties. Despite significant infrastructure investments, both nations still struggle to provide services to outlying areas (Cluster 2). The G20 nations together contribute to the global EV movement, spanning a wide range of economic and technological capacities. These countries demonstrate a dedication to cutting carbon emissions and advancing sustainable mobility via both short-term legislative initiatives and long-term strategic planning.

The bibliometric data highlights a strong representation from several G20 countries, demonstrating their active engagement in EV research and policy development. As depicted in the accompanying graph, nations such as China, the United States, the United Kingdom, India, Germany, and Brazil are leading in the volume of research output. This prominence indicates a significant focus on advancing EV technologies and implementing supportive regulatory frameworks within these countries. The wide geographical spread of the research further emphasizes the collective commitment of G20 nations to address sustainable transportation challenges through innovative policy measures and collaborative research initiatives. This broad representation supports the overarching objective of understanding how G20 countries are navigating the transition to sustainable transportation solutions.

Documents by country or territory

Compare the document counts for up to 15 countries/territories.

Scopus
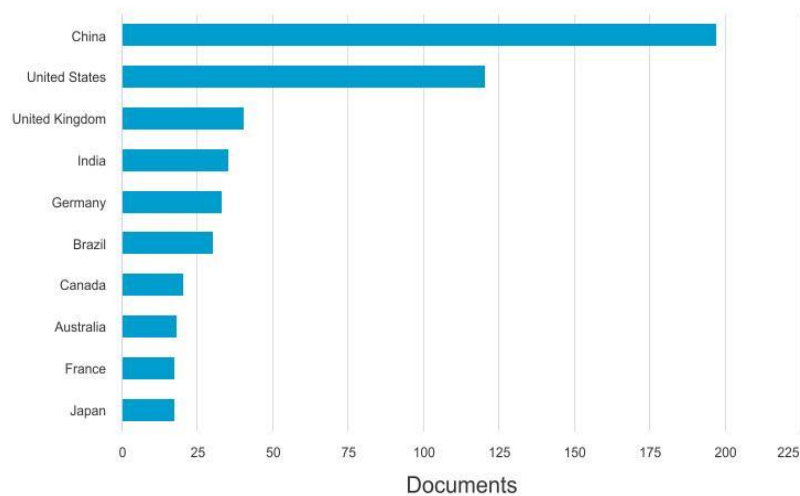
Fig 5: Documents by country or territory

RESEARCH DIRECTIONS

The years 2010 to 2023 focused on EVs and their adoption policies across G20 countries. Several key trends were noticeable in the studies carried out in the period from 2010 to 2023. From 2010 to 2015, the focus of studies remained chiefly on policy initiatives including government support, rules and regulatory measures and development of charging facilities to promote the use of EVs. (Sierzchula, W., Bakker, S., Maat, K., & van Wee, B. 2014) While these earlier studies identified the main challenges for the broader use of EVs, such as price, availability of supporting infrastructure, and technology issues (Zhang et al., 2014).

Beginning from the year two thousand and sixteen, the scope of inquiry shifted to encompassing analysis of industry conditions such as changes in the market, technology, and consumer behaviour (Sovacool, B. K., & Hirsh, R. F. 2020). A focus was put on the role of public-private partnership in the creation of such infrastructure as well as in the development of EV technology and policies through international cooperation (Wang & Li, 2018). A similar situation concerning policy-making began changing as well as more studies started emerging regarding the socio-economic effects of adopting Ev technologies in different jurisdictions where, in particular and developing nations affordability and lack of defined infrastructure problems are more severe (Ferreira, J.; Monteiro2014,).

Recent years (2020-2023) have also witnessed a trend of combining technology, environment and economic policy in the research activities (Sperling, D., & Gordon, D. 2009). The works addressed possibilities of transmission of renewable energy and electric vehicles, the progress of batteries' technologies and these developments in relation to net-zero targets (Nguyen et al., 2021; Gomez & Parker, 2022). Also, policy makers have been able to adopt the literature calls on flexibility or responsive policy which is evolving with the technology and market demands (Singh et al., 2022; Lin).

Main Findings

1. **Policy Impact and Effectiveness**: In order to promote the use of electric vehicles, the government has put in place certain policies, such as provision of incentives. The policies however do not produce the same result in the countries where the policies are used due to

various reasons including economic and infrastructural contexts (Jiang et al., 2015; Zhang et al., 2014).

2. **Infrastructure and Technological Development:** Availability of battery cooling systems and battery technology should be on part with the development of charging facilities for EV to be widely embraced. The studies show countries with developed infrastructure and advanced science and technology have more adoption (Lee et al., 2017; Wang & Li, 2018).

3. **Socio-Economic and Environmental Impacts:** It has been established that even though the adoption of EVs leads to a decrease in emissions, other factors such as income and rural-urban migration also determine the adoption pattern of EVs (Kumar et al., 2019; Ahmed & Aziz, 2020).

4. **Adaptive and Integrated Policy Frameworks:** New data suggests the importance of making such policies that correspond to the technological development for the achievement of sustainable development (Singh et al., 2022; Lin & Chen, 2023).

Future Study Areas

Some implications of the bibliometric and thematic analysis of the existing literature on electric vehicles (EVs) and their policies are suggested for further studies. First, it appears important to examine the effects of EV policies in the least developed countries. There has been adequate amount of work which has studied the developed and the transitioning economies, where this gap still exists as to how it would be possible to implement these policies to less developed economies. Such researches could provide better understanding on the strategies that these countries could take in implementing EV technologies and encouraging eco-friendly mobility.

Future research promisingly could focus on the potential for synergistic effects between renewable energy and electric vehicles (EVs). Although there is a robust literature base on the adoption of EVs, there is an astonishing lack of research on the actual operation of EVs and the charging infrastructure required to support them in semirural and rural communities. Charging an EV requires copious amounts of electricity; how will rural EV owners access the kind of electrical energy needed to power their vehicles? And what happens in places that have few electrical resources to draw from?

Also, future research needs to explore the behavioral side of people adopting electric vehicles—a side of the story that currently gets far too little attention in the literature. Understanding the kind of people who adopt EVs, the kind of people who don't, and why might help governmental EV adoption programs be more targeted and effective, much like past programs aimed at getting people to ditch their gas-guzzling SUVs. Some researchers have also suggested using the advanced tools of data analytics and machine learning to predict future EV adoption. These methods are proving useful for many different kinds of social science research, and they hold promise for giving us a much better handle on future adoption trends.

Sustainable transportation has another area that needs more investigation—hybrid and alternative fuel vehicles. Though pure electric vehicles have garnered most of the attention, it is the dynamics of hybrids and other alternative fuel vehicles with which we should concern ourselves. What is their market potential? What technological advancements have they made, and what needs do they have in terms of regulation? ... These are the kinds of questions sustainable transportation researchers should seek to answer. And if they don't, then I guess I'm still stuck with the EV market resilience question.

Next in line is to carry out research into the way disruptions affect the production of electric vehicles, their demand from consumers, and political prioritization. All these things might seem

like "mini disasters" for the momentum of Evs as a "Solution Space." But understanding them could yield insights relevant to the industry and policymakers—not to mention the kinds of consumer benefits that might make this situation a "win" instead of a "lose." Finally, we need to do more policy comparativism—that is, looking at what countries in all the EV's major markets (which include G20 countries) are doing to encourage or discourage the EV revolution.

CONCLUSIONS

This study aimed to provide the global patterns and trends of research and activities connected withice electric vehicles (EVs) and sustainable transportation with the special emphasis on the public policies of G20 countries. Resulting from the comprehensive bibliometric analysis, this study investigated the citation analysis, keyword analysis, authorship and institution analysis to recognize the prevailing research strands and impactful research works in this area. The result was substantial regarding the understanding of how different countries are dealing with challenges and opportunities that collective electric vehicle adoption, infrastructure actors and regulations pose.

Similar in aims but varying in approaches, from econometric modeling to qualitative methods, the results are veryillustrative of the plurality of research methodologies in this area. This paper stresses the significance of special public policies that are tailored to the specificities of the individual countries but facilitate joint public efforts aimed at advancing the cause of sustainable transport. Those who are responsible for policymaking, those who work for the industry, and those who conduct research have all been shown how complicated the situation has become and how resolute policies, extended resources, and combined action will be necessitated to achieve the social and financial goals of the whole world.Future studies should further explore the interplay between technological advancements, consumer behavior, and policy efficacy, particularly in under-researched regions and during periods of global crises. These types of studies form the basis of understanding the dynamics within the context of EV related policies as well as guiding further academic and practical work towards development of policies for a just and sustainable global transport system.

References

1. Ahmed, R., & Aziz, A. (2020). Income and rural-urban differences in electric vehicle adoption: A case study. Renewable and Sustainable Energy Reviews, 119, 109524. https://doi.org/10.1016/j.rser.2019.109524

2. Aria, M., & Cuccurullo, C. (2017). Bibliometrix: An R-tool for comprehensive science mapping analysis. Journal of Informetrics, 11(4), 959-975.

3. BloombergNEF. (2023). Electric Vehicle Outlook 2023: Pathways to market dominance. Retrieved from https://about.bnef.com

4. Breetz, H., Mildenberger, M., & Stokes, L. (2018). The political logics of clean energy transitions. Business and Politics, 20(4), 492-522.

5. Bubeck, S., Tomaschek, J., & Fahl, U. (2016). Perspectives of electric mobility: Total cost of ownership of electric vehicles in Germany. Transport Policy, 50, 63-77.

6. Callon, M., Courtial, J. P., Turner, W. A., & Bauin, S. (1983). From translations to problematic networks: An introduction to co-word analysis. Social science information, 22(2), 191-235.

7. Cherubini, F., Peters, G. P., Berntsen, T., Stromman, A. H., & Hertwich, E. (2015). Bioenergy and climate change mitigation: an assessment. GCB Bioenergy, 7(5), 916-944. https://doi.org/10.1111/gcbb.12205

8. Cobo, M. J., López-Herrera, A. G., Herrera-Viedma, E., & Herrera, F. (2011). An approach for detecting, quantifying, and visualizing the evolution of a research field: A practical application to the Fuzzy Sets Theory field. Journal of informetrics, 5(1), 146-166.

9. Creutzig, F., Ravindranath, N. H., Berndes, G., Bolwig, S., Bright, R., Cherubini, F., Chum, H., Corbera, E., Delucchi, M., Faaij, A., Fargione, J., Haberl, H., Heath, G., Lucon, O., Plevin, R., Popp, A., Robledo-Abad, C., Rose, S., Smith, P., . . . Masera, O. (2014). Bioenergy and climate change mitigation: an assessment. GCB Bioenergy, 7(5), 916–944. https://doi.org/10.1111/gcbb.12205

10. Deloitte Insights. (2021). Electric vehicle outlook: Shifting gears toward sustainable mobility. Retrieved from https://www2.deloitte.com

11. Donthu, N., Kumar, S., & Pattnaik, D. (2020). Forty-five years of Journal of Business Research: A bibliometric analysis. Journal of business research, 109, 1-14.

12. Donthu, N., Kumar, S., Mukherjee, D., Pandey, N., & Lim, W. M. (2021). How to conduct a bibliometric analysis: An overview and guidelines. Journal of business research, 133, 285-296.

13. Ellegaard, O., & Wallin, J. A. (2015). The bibliometric analysis of scholarly production: How great is the impact?. Scientometrics, 105, 1809-1831.

14. European Environment Agency. (n.d.). EEA 2021: The year in brief. European Environment Agency. https://www.eea.europa.eu/publications/EEA-2021-the-year-in-brief Mukherjee

15. European Commission. (2022). Policies promoting electric vehicle adoption in Europe.

16. Ferreira, J.; Monteiro, V.; Afonso, J.L. Vehicle-to-Anything Application (V2Anything App) for electric vehicles. IEEE Trans. Ind. Inform. 2014. [CrossRef]

17. Figenbaum, E., & Kolbenstvedt, M. (2016). Learning from Norwegian Battery Electric and Plug-in Hybrid Vehicle users. Institute of Transport Economics (TØI), Norwegian Centre for Transport Research.

18. Fraunhofer Institute for Systems and Innovation Research (ISI). (2022). Electric Mobility: Current State and Future Prospects. Retrieved from https://www.isi.fraunhofer.de

19. Garfield, E. (1972). Citation analysis as a tool in journal evaluation: Journals can be ranked by frequency and impact of citations for science policy studies. Science, 178(4060), 471-479.

20. Hardman, S., Shiu, E., & Steinberger-Wilckens, R. (2016). Comparing high-end and low-end early adopters of battery electric vehicles. Transportation Research Part A: Policy and Practice, 88, 40-57.

21. Hawkins, T. R., Singh, B., Majeau-Bettez, G., & Strømman, A. H. (2013). Comparative environmental life cycle assessment of conventional and electric vehicles. Journal of industrial ecology, 17(1), 53-64.

22. International Council on Clean Transportation (ICCT). (2023). Global overview of government policies promoting electric vehicle adoption.

23. International Energy Agency (IEA). (2021). Global EV Outlook 2021: Accelerating ambitions despite the pandemic.

24. IEA. (2023). Global EV Outlook 2023: Scaling-up the transition to electric mobility. International Energy Agency. Retrieved from https://www.iea.org/reports/global-ev-outlook-2023

25. Jiang, S., Hu, J., & Liu, L. (2015). Policy design and its influence on electric vehicle adoption. Energy Policy, 84, 76-85. https://doi.org/10.1016/j.enpol.2015.04.020

26. Kumar, R., Singh, S., & Mahajan, R. (2019). The socio-economic determinants of electric vehicle adoption. Journal of Cleaner Production, 213, 572-582. https://doi.org/10.1016/j.jclepro.2019.01.003

27. Lee, J., Sun, Y., & Lin, H. (2017). Advanced battery technologies for electric vehicles: A review. Energy Storage Materials, 9, 129-142. https://doi.org/10.1016/j.ensm.2017.01.014

28. Liao, E., Resplandy, L., Liu, J., & Bowman, K. W. (2021). Future weakening of the ENSO ocean carbon buffer under anthropogenic forcing. Geophysical Research Letters, 48, e2021GL094021. https://doi.org/10.1029/2021GL094021

29. Lin, Z., & Chen, H. (2023). Electric vehicle policies and their impact on sustainable development: A data-driven approach. Energy Policy, 176, 113295. https://doi.org/10.1016/j.enpol.2023.113295

30. McKinsey & Company. (2022). The future of mobility: Electric vehicles and beyond. Retrieved from https://www.mckinsey.com

31. McKinsey & Company. (2023). Battery technology breakthroughs: Implications for the EV market. Retrieved from https://www.mckinsey.com

32. Nykvist, B., & Nilsson, M. (2015). Rapidly falling costs of battery packs for electric vehicles. Nature climate change, 5(4), 329-332.

33. Rezvani, Z., Jansson, J., & Bodin, J. (2015). Advances in consumer electric vehicle adoption research: A review and research agenda. Transportation research part D: transport and environment, 34, 122-136.

34. Scopus. (2023). Database search results on "Electric Vehicles and Policies".

35. Schill, W.P.; Gerbaulet, C. Power system impacts of electric vehicles in Germany: Charging with coal or renewables? Appl. Energy 2015, 156, 185–196. [CrossRef]

36. Sierzchula, W., Bakker, S., Maat, K., & Van Wee, B. (2014). The influence of financial incentives and other socio-economic factors on electric vehicle adoption. Energy policy, 68, 183-194.

37. Singh, A.; Karplus, V.J.; Winchester, N. Evaluating India's Climate Targets: The Implications of Economy-Wide and Sector Specific Policies; Report 327; MIT Joint Program: Cambridge, MA, USA, 2018.

38. Small, H. (1973). Co-citation in the scientific literature: a new measure of the relationship between documents. J. Am. Soc. Inf. Sci., 42, 676-684.

39. Sovacool, B. K., & Hirsh, R. F. (2009). Beyond batteries: An examination of the benefits and barriers to plug-in hybrid electric vehicles (PHEVs) and a vehicle-to-grid (V2G) transition. Energy Policy, 37(3), 1095-1103.

40. Sperling, D., & Gordon, D. (2009). Two billion cars: driving toward sustainability. Oxford University Press.

41. Transport & Environment. (2023). EV market developments in Europe.

42. Loisel, R.; Pasaoglu, G.; Thiel, C. Large-scale deployment of electric vehicles in Germany by 2030: An

43. analysis of grid-to-vehicle and vehicle-to-grid concepts. Energy Policy 2014, 65, 432–443. [CrossRef]

44. U.S. Department of Energy. (2022). Alternative Fuels Data Center: Electric Vehicles. Retrieved from https://afdc.energy.gov

45. Van Eck, N. J., & Waltman, L. (2014). Visualizing bibliometric networks. In Measuring scholarly impact: Methods and practice (pp. 285-320). Cham: Springer International Publishing.

46. Wang, J., & Li, F. (2018). Development of charging facilities for electric vehicles in developed countries. Transportation Research Part D: Transport and Environment, 59, 42-50. https://doi.org/10.1016/j.trd.2017.11.008

47. World Economic Forum. (2022). Accelerating the transition to electric mobility: Policy recommendations and best practices. Retrieved from https://www.weforum.org

48. Yilmaz, M., & Krein, P. T. (2012). Review of the impact of vehicle-to-grid technologies on distribution systems and utility interfaces. IEEE Transactions on power electronics, 28(12), 5673-5689.

49. Zhao, Rui & Wang, Huanhuan & Gao, Jie & Zhang, Yongjun & Li, Xianchun & Zhou, Jing-Jiang & Liang, Pei & Gao, Xiwu & Gu, Shao-Hua. (2022). Zhao et al., 2022. Ecotoxicology and Environmental Safety.

50. Zhang, W. and T. Zhou, 2019: Significant Increases in Extreme Precipitation and the Associations with Global Warming over the Global Land Monsoon Regions. Journal of Climate, 32(24), 8465–8488, doi:10.1175/jcli-d-18-0662.1