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Sustainable development of electric vehicles in China: A bibliometric analysis and systematic review, 2011 onward

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Abstract: To address the challenge of climate change, China declared that its carbon dioxide emissions would peak in 2030 and become carbon neutral by 2060. China is the largest energy supplier and electric vehicles market worldwide and will stop selling combustion vehicles by 2035 and completely phase them out by 2050. To provide a overview of the current research, a bibliometric analysis and systematic review were conducted. The bibliometric analysis utilized data from Web of Science and Scopus, selected based on the PRISMA guidelines. Focusing on studies conducted in China and related to social sciences, environmental sciences, business, or economics. A total of 188 articles met the inclusion criteria. The analysis was performed using VOS viewer software to map co-citations and keyword co-occurrences, identifying core research themes and prominent clusters in the field. However, most researchers have primarily focused on one or two aspects of sustainability, with the hot spots being subsidies, charging costs, charging infrastructure, charging stations, batteries, and emissions. Life cycle assessment is also the most applied theory. This study recommended future research to focus on the usage stage of EVs, incorporating all three sustainability pillars. Additionally, regional assessment should be conducted to consider regional characteristics such as temperature, how policy influences affect electric vehicle emissions, social impacts, and economic advantages. Before promoting electric vehicles, regional assessments should be conducted, so that stakeholders can make decisions.

Keywords: *Bibliometric analysis, Carbon neutrality, Electric vehicles, Life cycle assessment, Sustainable development.*

1. Introduction

Greenhouse gas (GHG) emissions are a primary factor contributing to global warming, with transportation being a major source, accounting for 19.5% of GHG emissions in the European Union 2). Effective urban transportation systems, integrating elements like public transit and non-motorized travel, are essential for sustainable growth (3).

Electric vehicle has steadily expanded on a global scale in recent years, promote the switch to electric vehicles in order to improve air quality, combat climate change, and promote industrial development (4). China has stated that it will stop selling combustion-powered vehicles in 2035 and completely phase them out by 2050 (5). China continues to speed up the promotion of electric vehicles through governmental incentives and advances longer-term objectives for electric vehicle development as the world's largest auto and electric vehicle market (6).

2. Research Methodology

Because of their wider coverage, Web of Science and Scopus have been considered the two main choices for bibliometrics and literature reviews (7). These criteria for selection were based on the Preferred Items for Systematic Review and Meta-analysis (PRISMA) Statement (8). This study focused mainly on retrieving the relevant literature in the fields of development business, economics,

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environmental science, and social science of sustainable electric vehicles. Articles published between 2011 and 2021 were considered in the review. Since the search focused primarily on China, all studies conducted in other countries were excluded. Each article was read carefully, paying close attention to the keywords, titles, and abstracts. Duplicated articles were identified and removed accordingly. The included articles fulfilled the following inclusion criteria: 1. An original paper, review paper, or conference paper. 2. The article must be written in English and related to the following fields: social sciences, environmental sciences, business or economics. 3. Articles published between 2011 and 2021. 4. Studies conducted in China. Based on the listed inclusion criteria, a total of 188 articles were included in this study. Selected careful after analyzing each item in light of the aforementioned inclusion and exclusion standards. Figure 1 demonstrates the literature that is included and excluded at each.

The final study phase mainly involved an Excel-based descriptive analysis (9) and bibliometric research using the Visualization of Similarities (VOS) method. Based on direct citation relationships, VOS elicited homogeneous groupings of scientific contributions. VOS viewer version 1.6.10 was used to run the main portion of the analysis (10). The degrees of similarity derived by the two relatedness assessments were correlated.

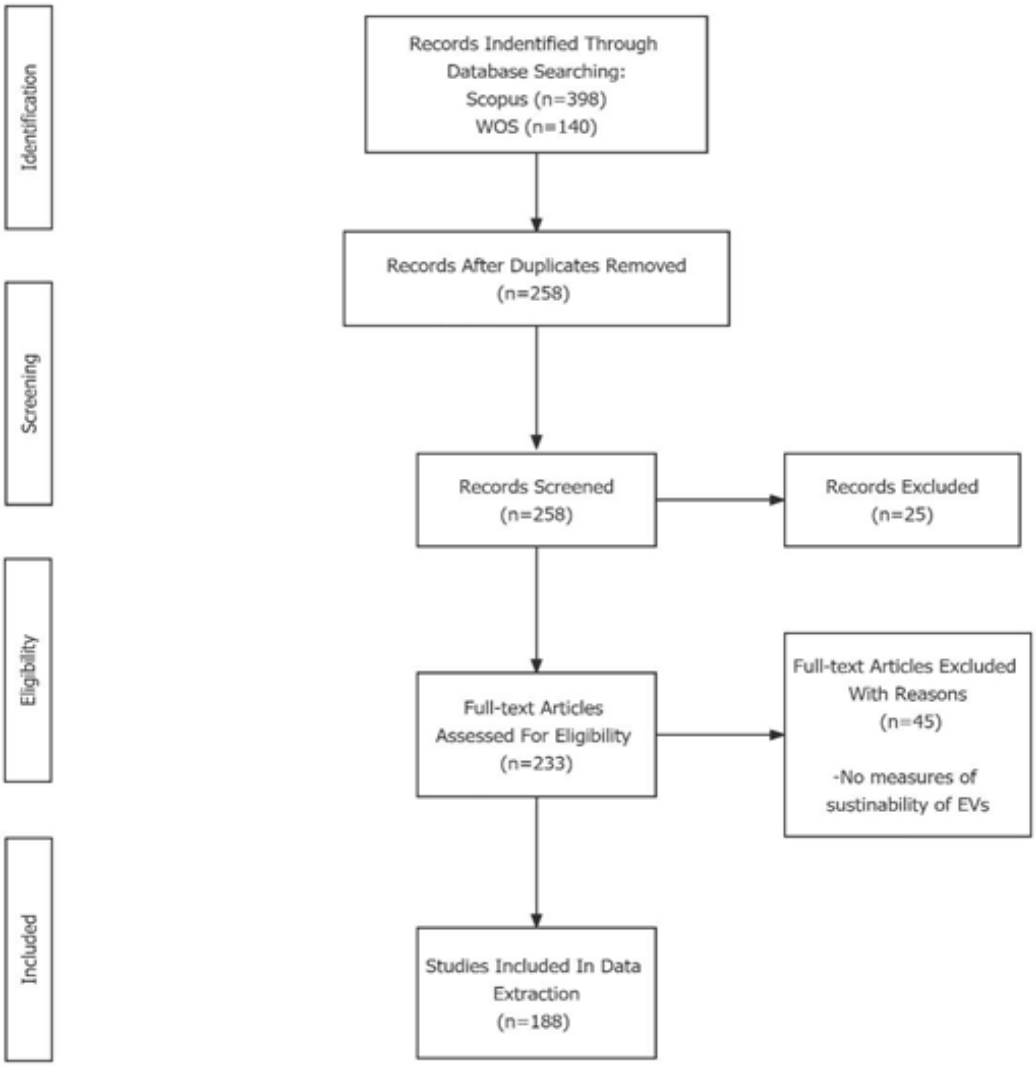

Figure 1.
Demonstrates the literature that is included and excluded at each level.

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3. Reporting Results

3.1. Descriptive Analysis

The data was analyzed descriptively using Excel software (9). The result depicts the amount of attention academics paid to the sustainable development of EVs, specifically reflecting an upward trend during the period 2012–2021. Since 2012, only a small variation was observed in the number of published articles on sustainable development of EVs. The most linear growth of published articles was recorded between 2020–2021, ranging from 31 to 68, which might be linked to General Secretary Xi Jinping's declaration that "China will increase its nationally determined contribution, adopt more powerful policies and measures, and strive to peak carbon dioxide emissions before 2030" during the general debate of the United Nations General Assembly. China aims to become carbon neutral by 2060 as stated on September 22, 2020. The field's exponential expansion reflects that there will be more discussion on how to achieve sustainable EV development and use.

505 citations are found in the article with the greatest citation count. The studies that rank in the top 10 are very multidisciplinary. Despite its novelty and apparent concentration of influence in a small number of papers, and high level of political interest in the field of inquiry, publications concerning the sustainability of EVs have received a lot of citations. Citations are a helpful measure of how much consideration and attention an article receives. An important signal for writers and researchers is an increase in citations, which suggests that the study is worthwhile to pursue in the future (11). Since it affects every country to a considerable extent, the trend indicates that in the years to come, discussions about social, economic, and environmental issues will still center around this topic. Table 1 lists the top 10 record journals for each of the included papers. The journals that the majority of researchers choose to publish in and the ones that have the most pertinent papers are summarized in the table. Researchers may find this information useful in the future when choosing which journals to submit their work to.

Table 1.
Top ten record journals.

Number	Journal	Records
1	IOP Conference Series: Earth and Environmental Science	30
2	Journal of Cleaner Production	28
3	Sustainability	17
4	Applied Energy	10
5	E3S Web of Conferences	10
6	Resources Conservation and Recycling	10
7	Energy	5
8	Science of the Total Environment	5
9	Sustainable Cities and Society	5
10	Energy Policy	4

3.2. Network Analysis

Originating in scientific metrics to quantitatively survey academic literature based on bibliographic data (12), co-citation analysis is a well-known, literature-based method with a long history of use for examining the intellectual organization of scholarly areas and the traits of scholarly communities(13). The studies of bibliographic coupling of articles, journals, and authors are presented in this subsection. VOS Viewer (10) by creating relevant linkages, network analysis has been used to the 188 papers as part of bibliometric study.

3.2.1. Co-Citations

Henry Small (1973) developed the co-citation method for network analysis, which is defined as the number of times two earlier works are cited together in a later work (14). The results, visualized in

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network diagrams, use circle size to represent citation frequency and line thickness to indicate the strength of co-citation relationships among articles, helping to identify key research clusters (15).

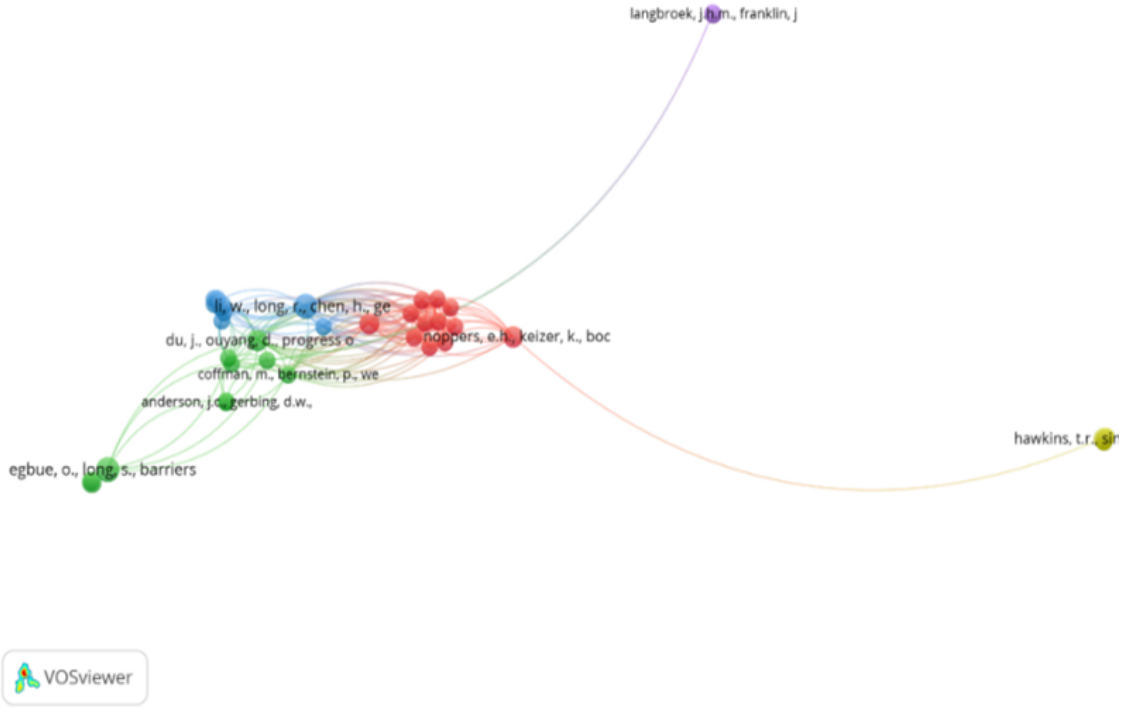

Figure 2.
Co-citations of EVs sustainability study.

Co-citation analysis, performed using VOS viewer, counts how often two documents are simultaneously cited by later works, revealing relationships among research topics such as EV subsidies, charging infrastructure, and environmental effects. This analysis indicated five significant clusters, illustrating the interdisciplinary nature of EV research that spans sustainability, policy, and technology (16). Put differently, calculating the number of later texts that have cited the same pair of earlier texts is part of the co-citation analysis process. A co-citation analysis is carried out by using the co-citations analysis option in the VOSviever program when several articles quote the same articles. The unit of analysis is citations, and a cited reference must have a minimum of two citations. Only 72 of the 5488 mentioned references meet the required minimum of two citations. Using automation, five clusters were created (see Figure 2). This measure is considered an indication of the significant connection between the content of the co-cited publications.

3.2.2. Keywords Co-Occurrence

Research themes can be identified by analysing keyword frequencies. This involves grouping authors' keywords based on their co-occurrence frequency and forming a keyword co-occurrence network. When two keywords appear together in a title or abstract, they are considered to have co-occurred. In the co-occurrence map generated by VOS Viewer's "all keywords" feature, the proximity between two nodes is inversely proportional to their similarity, meaning that terms that frequently co-occur are placed closer together (17).

The total strength of the co-occurrence linkages with other keywords will be requires a minimum of five occurrences and ggiven that the keywords with the most total links will be chosen, only 94 were selected and organized into 6 clusters. The most often used terms in this network are sustainable development, planning, and environmental protection, as seen in Figure 3.

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The power and importance of these keywords are illustrated by the lines that link them. Since these terms are frequently used when discussing the sustainable development of EVs, the result was anticipated. However, there are other significant combinations including "sustainability -life cycle assessment", "commerce- carbon emission", "recycling – economic and social effects". "Environmental impact – climate change". These connections depict that academics are considering other aspects of sustainability, such as batteries, charging, planning, and product life cycle, while studying the sustainable development of EVs, in addition to the environment. When keywords are grouped, it indicates that they are more likely connected to the same subject or theme (18).

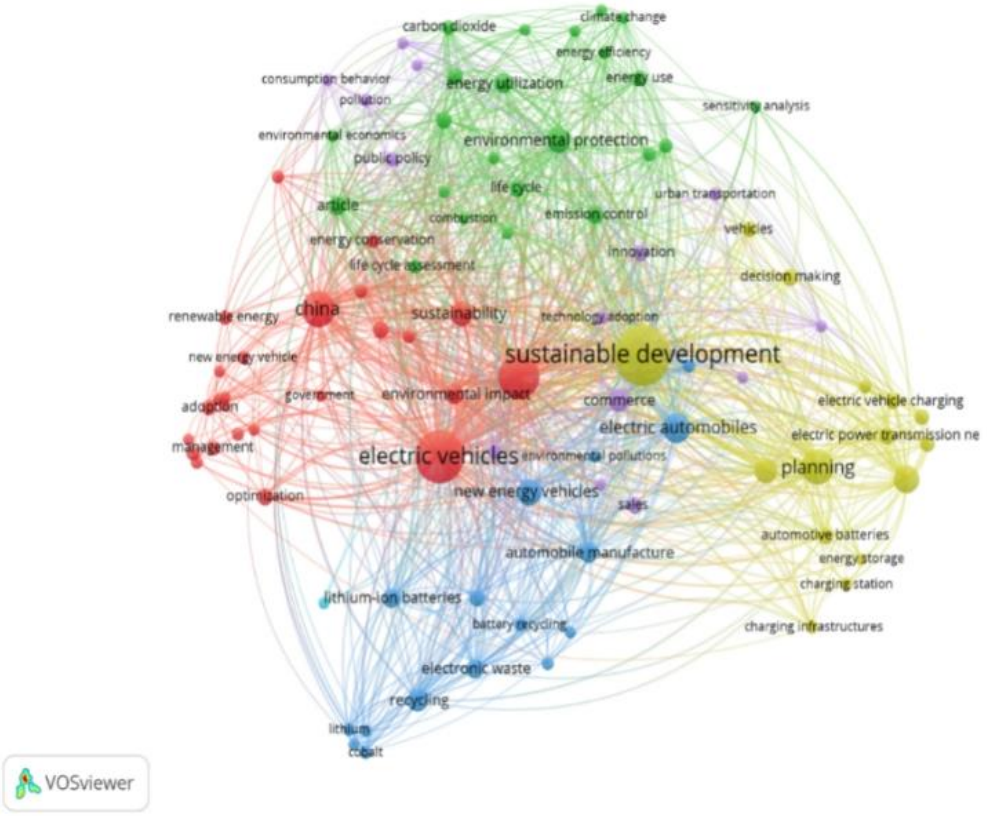

Figure 2.
Keywords Co-occurrence of EVs study.

3.3. Mapping Existing Literature

From this study fund that subsidy for Evs; charging price; charging stations; batteries of EVs; EVs emissions is most popular topic researcher study, we describe each topic bellow. The prevalent use of life cycle assessment in EV research reflects its importance in understanding environmental impacts comprehensively. However, the emphasis on environmental factors over social and economic dimensions suggests a need for more holistic sustainability evaluations. Future research should focus on integrating economic and social assessments to provide a more balanced view of sustainability in EV development.

3.3.1. Subsides and Pricing

Increased subsidies are the only way to improve market efficiency (19).While subsidies enhance the economy, they also increase pollution and demand for technology. They claim that encouraging technical innovation is more sustainable than funding (20,21). A careful price strategy and subsidy policy can change the collaboration mode from any state to the desired aim. The reward-penalty system

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affects recycling and society's welfare more than the subsidy approach, which relies on consumer excess and EV manufacturers' revenues (22). The subsidy rate must be sufficient for complete NEV diffusion (23) Implementing the new energy vehicle pilot strategy in China has stimulated innovation and the enforcement of pollution reduction legislation. However, it has also resulted in a deceleration of green technology development (24).

Stricter new energy vehicle credit goals may boost manufacturing while limiting internal combustion engine automobile sales (25). If the domestic car arrives later, it can gain more market share (22). Zhao's research highlights the restriction on the owner of a private charge pile's unilateral pricing compared to an electricity provider or an EV user (26). Therefore, the best pricing cannot be reliably calculated using the unilateral bargaining model. To determine the final charging cost, add unilateral pricing to that of power retailers and electric vehicle users. Large NEV enterprises can increase output with financial and governmental support. For the NEV industry to progress technologically, more government backing is needed from small businesses that drive technical innovation. This is the only way the government can reduce city pollution and boost the NEV market (27). Later entrants will have new entrance possibilities due to the early entrant's market uncertainty, technology change, and customer demand dynamics (28).

3.3.2. Charging Infrastructure

Charging networks need careful city-level planning (29). EV initiatives are expanding worldwide as renewable energy and sustainability gain importance (Liu & Wei, 2018). To increase electric vehicle sales, charging infrastructure, including stations, must be well-designed (31), where the position of the charging station is critical for an electric vehicle company's sustainable growth (32) suggests a fuzzy multi-criteria decision-making (MCDM) approach for selecting the location of charging stations. Hardinghaus et al., (2018) (31) suggests should also pursue province-specific electric grid and plug-in vehicle technology development plans to reduce greenhouse gas emissions in on-road transportation (33). Li et al., （2021) (19) suggested coordinating China's EV charging system standards with the International Electrotechnical Commission to improve global standardization. Time-sharing pricing and time division are employed to charge and meet EV demand. It may reduce charging costs and load fluctuations, boosting system reliability and efficiency (34).

EV batteries are rapidly approaching the end of their useful lives due to their growing popularity, which has raised significant issues for environmental preservation and sustainable development (22). Given the retirement of China's NEV power batteries, the recycling and gradient utilization (GU) of these batteries are crucial for supporting the sustainable development of the economy, society, and environment in the long term (35).

3.4. EVs Emissions and Life Cycle Assessment

EVs life cycle emission controversial, some of researchers agree EVs have sustainability but some are disagreed. Cai et al., (2017) (36) point out ICEVs in China have better life cycle sustainability than BEVs. Due to battery manufacturing energy consumption and emissions, electric vehicles have more significant life cycle primary energy consumption and greenhouse gas emissions than fuel cell and internal combustion engine vehicles (Yang et al., 2020).

But Zeng et al., (2021) (38) get results on BEVs and plug-in hybrid electric vehicles (PHEVs) driven by the typical Chinese energy mix reduce global warming potential. However, increasing ecological and human toxicity, mineral resource shortages, and other issues are the price. Luk et al., (2019) (39)mentions that pure electric car uses the same energy as a gasoline-powered one. Pure electric vehicles emit less energy since they use 52.2% less energy than gasoline-powered cars. According to Hou, passenger battery electric automobiles could reduce greenhouse gas emissions by 40–215 Mt CO_2eq and 340–1380 Mt CO_2eq. This will help limit global warming and transition the transportation industry to a low-carbon economy (40).

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Cai recommended improving the city's taxi fleet by employing a hybrid life cycle approach combined with multi-criteria decision analysis. The environmental, financial, and political impacts of different vehicle kinds would be easier to assess (36). Driving less could significantly reduce Chinese urban families' global warming potential (GWP) (41). Moreover, turn to green consumption patterns: fewer car trips, longer equipment lifespans, and electricity savings reduced household GWP (16).

3.5. Limitations and Gaps

The review highlights a significant concentration on technological and policy aspects, with less attention to consumer behavior and market dynamics. It is recommended that future studies explore these areas to understand the broader implications of EV adoption. Additionally, extending the scope beyond China could provide comparative insights and foster global policy alignment. Most of the articles included in this review focused on co EV subsidies, charging costs, EV charging stations, EV batteries, and EV emissions; whereas only a few emphases the most important stage, which is the use stage to ascertain whether or not sustainability (environmental, social, and economic) is present in the cleaner stage. In addition, this study revealed that whereas most studies concentrate on one or two perspectives, sustainability is based on three pillars. Life cycle assessment (LCA) is often used as a key method for evaluating the environmental impact of product systems (43–45).

Sustainability concepts and evaluation techniques are now essential components of the strategic decision-making process for products, allowing for the early assessment of alternative commodities to guide decision-makers based on research outcomes (46). The life cycle sustainability assessment (LCSA) stands out as a promising method for this purpose, grounded in the Brundtland definition of sustainability (48;49). This method emphasizes the need to improve environmental, economic, and social dimensions concurrently, as they represent the three core pillars of sustainability (49).

LCSA method widely applied to assess the three pillars of sustainability: environmental, economic, and social factors (50). Because China is so large, the power composition in different power grids in China is different, so the air impact of using electric vehicles in different power grids is different. At the same time, temperature may have a great impact on the charging and discharging of electric vehicles. Social impact may affect the willingness to buy electric vehicles. So, promoting electric vehicles in an all-round way, regional assessments should be conducted to understand the environmental, economic and social impacts of electric vehicles in combination with regional characteristics so that stakeholders can make decisions.

4. Conclusion

This bibliometric review has elucidated the focal areas of EV sustainability research in China, aligning with global sustainability goals. As the field evolves, integrating comprehensive sustainability frameworks and expanding research horizons will be crucial in supporting the transition to low-carbon transportation systems worldwide. This review has mapped the key areas and gaps in the current research on EV sustainability in China. As the EV market continues to evolve, it is imperative that future research integrates comprehensive sustainability assessments, exploring economic, environmental, and social dimensions collectively to support the development of globally applicable sustainable transportation solutions.

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