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Knowledge Structure of New Energy Vehicle Policy Research

Mapping analysis and future research agenda

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Globally, transport is responsible for 23% of energy-related carbon dioxide emissions and 80% of these emissions are attributable to road transport. Significant transformations, including extensive electrification of the sector, are necessary to achieve climate change goals. To understand new energy vehicle (NEV) policy research, we explore the status, knowledge base and research frontiers of NEV policy research by studying 355 papers collected from the Web of Science™ (WoS) Core Collection database. We map NEV policy research trends and knowledge structure development using knowledge domain technology and bibliometric techniques. The knowledge base analysis shows that: (a) NEV policy formation and evaluation; (b) policy incentives and consumer adoption; and (c) consumer preferences towards NEV adoption are all essential knowledge foundations in NEV policy research and development (R&D). The efficiency of NEV policy, cost-effectiveness of alternative fuel vehicles (AFVs), consumer preferences for NEV adoption, hydrogen energy and fuel cell vehicles, climate policy and CO_2 emissions are five main lines of research in NEV policy studies. With the highest number of publications from Tsinghua University, China is the most active country in NEV policy research. *Energy Policy*, *Sustainability* and *Journal of Cleaner Production* are the core journals and Energy and Fuels and Environmental Sciences are the core disciplines of NEV policy research. The findings of this analysis help policymakers and researchers to navigate the literature on NEV, provide a clear map of existing works, identify the gaps and recommend promising avenues for future studies.

1. Introduction

Globally, 23% of the world's energy-related CO_2 emissions come from transport with 80% of these emissions originating from road transport (1). Road transport is a key sector in efforts to curb emissions. Nonetheless, it requires substantial shifts, including extensive electrification, to meet carbon reduction targets.

In the automotive sector, internal combustion engine vehicles (ICEV) are not only the primary source of travel and transportation but also the prime source of greenhouse gas (GHG) emissions. GHG emissions are critical factors worsening the environment and are responsible for climate change (2–4).

According to the US Environmental Protection Agency (EPA), there are 20 billion tonnes of GHG emissions worldwide, of which 29% are caused by the automobile sector (5). Considering environmental pollution and energy security, governments are anxious to go green by plummeting CO_2 emissions and fossil fuel dependency in the transport sector (6, 7). NEVs are a straightforward way to reduce fossil fuel reliance because of their low CO_2 emissions. In the meantime, worldwide use of NEVs can alleviate global warming and can help to achieve the goal of improving environmental problems. NEVs in this study refers to vehicles that use unconventional fuel as a power source. These include fuel cell electric vehicles, pure electric vehicles, hybrid electric vehicles (HEVs) and extended-range electric vehicles. The swift spread of NEVs gave unique development prospects because of their characteristics. According to the International Energy Agency (8), "the global electric vehicle fleet expanded significantly over the last decade, underpinned by supportive policies and technology advances". The number of electric cars on world's roads were 17,000 in 2010 and 7.2 million in 2019, of which 47% are on China's roads. The NEV industry has become a strategic emergent industry worldwide because it helps to achieve a net zero energy system by 2050.

For the development and promotion of the NEV industry, governments all over the world have launched different industrial policies. Norway and Japan have introduced financial and non-financial incentives to penetrate the NEV market. China, the USA, Japan and the European Union (EU) showed the efficient impact of incentives and regulatory policies on the NEV market. The Chinese government has implemented a series of different types of policies to stimulate NEV industry, i.e. economic instruments (R&D grants, subsidies, charging infrastructure), regulation instruments (patent laws, technology standards, market design) and information instruments (professional training, public information campaigns, cooperative R&D programmes). The NEV industry's production and sales have amplified with the help of these policy instruments (9). Thus, industry policies related to NEVs have a pivotal role and should be considered by academicians and policymakers.

Researchers have evaluated the effects of different policies on plummeting CO_2 emissions in the road transport sector (10), NEV development (11) and CO_2 emissions (12–14). Some scholars have studied the impact of policy mixes and interactions on the macroeconomy and industry (15) and the diffusion of battery electric cars (16). Qiu *et al*. (17) study the impact of policy shifts such as halting the subsidy policy on the NEV industry in China. Therefore, the research on NEV policies has specific groundwork. Scholars have evaluated the policy documents (9), their pivotal role in decarbonising the global economy (18) and their impact on the development of the NEV industry. However, to the best of our knowledge, the bird's eye view of research status of NEV policies have not been addressed using mixed method techniques (bibliometric and qualitative thematic analysis).

The data sample is collected from the WoS Core Collection Database. In this study, we first assess the performance of NEV policy research, second, its evolutionary paths and third, its future research arenas. Based on this purpose we address the following research questions in the study:

- RQ1: what is up-to-date status of NEV policy research?
- RQ2: what are evolutionary paths of knowledge structure of NEV policy research?
- RQ3: what are future research directions of NEV policy research?

The Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA) protocol has been recognised to enhance reliability and validity of findings. Following this protocol, criteria were implemented to choose articles for inclusion; our sample consists of 355 studies over 21 years (2000 to 2021). Then, a mixed-method tactic was applied, including bibliometric analysis (quantitative) and thematic analysis (qualitative).

We used a bibliometric approach to: (a) identify publication outlets and trajectories; and (b) identify the most cited authors with substantial contributions to NEV research. Thus, this analysis explains how the pieces of evidence are interconnected, revealing the field's current research development and structure. Moreover, we use thematic content analysis to identify research themes based on intellectual contexts and make compelling inferences. The objective of this study is threefold. Firstly, we use a mixed-methods approach to evaluate the NEV policy research comprehensively and systematically with a sizable number of research articles. The thematic content analysis (qualitative) and bibliometric analysis (quantitative) fill in the limitations and gaps of the previous research. Secondly, based on our sample, we use the knowledge mapping method

to envisage the evolutionary path of NEV policy research. With the help of this method, we reveal the dynamics of the NEV policy knowledge base. Thirdly, we address the future research directions on NEV policy research using a mixed method approach.

The contribution of this study is threefold. Firstly, we use qualitative and quantitative methods to evaluate the NEV policy research comprehensively and systematically with a sizable number of research articles. The qualitative and quantitative analysis atone for the limitations and shortcomings of the previous research. Secondly, based on 355 articles on NEV policy research, we use the knowledge mapping method to envisage the evolutionary path of NEV policy research. With help of this method, we reveal the dynamics of NEV policy knowledge base. Thirdly, we address the future research directions on NEV policy research by using bibliometric and thematic analysis techniques.

The remainder of this paper is structured as follows: Section 2 explains the methods used in this study. Section 3 describes the main findings of the up-to-date status of NEV policy research in terms of temporal and spatial distribution of research, citation and co-citation analysis and co-authorship analysis. Additionally, it explains the findings of the evolutionary path of NEV policy research in terms of research hotspots, frontier analysis and the future research direction of NEV policy research. Section 4 presents the study's discussion, future research directions and conclusion.

2. Methods and Analysis

PRISMA protocol is used to facilitate reporting of systematic reviews (19), which is frequently used in literature review papers. The PRISMA protocol comprises of four steps: (a) identification implies all the databases and items associated with the selected topic; (b) screening removes the duplicated material and shrinks the number of items; (c) eligibility follows a comprehensive description of the exclusion and inclusion criteria; (d) the study inclusion step focuses on including the number of articles in the sample which will be part of qualitative and quantitative analysis. The PRISMA framework certifies that the papers included in the sample are transparent and provide a reference point for other researchers in the field (3).

Various databases have been used for bibliometric analysis i.e. Google Scholar, Scholar or ProQuest. However, studies suggest that WoS is an ideal database for bibliometric analysis (20), having more than 1 billion cited reference connections and almost 100 years of widespread coverage. WoS has been expansively adopted in NEV research (3). Thus, we consider it a rich and appropriate source for this study.

To excerpt NEV studies, we used the syntax ("new energy vehicle*" OR "hybrid energy vehicle*" OR "hydrogen energy vehicle*" OR "battery electric vehicle*" OR "fuel cell vehicle*") AND ("policy*") and we found 1,891 articles, proceeding papers, review articles and book chapters as of August 2021. We limited the article number to 1,215 based on: (a) document type "articles and review papers"; (b) publication year "2000–2021"; (c) language "English"; (4) WoS indexing "Social Science Citation Index" and "Social Science Citation Index Expanded". Though we carefully selected the keywords, some discrepancies were not noticed. Therefore, we examined the selected articles' titles, abstracts and keywords with the help of Microsoft Excel filter and macro options to confirm whether the selected articles discussed the NEV policy in a clear and sturdy context and deleted the identical and irrelevant articles. This process of inclusion and exclusion of documents enables us to cover the topic's domain explicitly (21). We finally selected a total of 355 documents. The PRISMA flowchart is shown in **Figure 1**.

The three research questions, as explained in the introduction, are answered by the following methods: (a) the up-to-date status of NEV policy research is identified by descriptive analysis, i.e. the temporal distribution of documents (NEV literature publication globally, publication growth trend by active nations), the spatial distribution (the most productive countries and regions, disciplines, institutions and journals); (b) the evolutionary path of NEV policy research is first explained by network visualisation (co-authorship analysis, citation analysis and co-citation analysis of references and journals) and then by keyword co-occurrence analysis and research frontier analysis; (c) the future research trends of NEV policy research are identified by using keyword co-occurrence and a qualitative approach, i.e. thematic content analysis, to identify the future research trends in NEV policy research as suggested by Khan *et al*. (21).

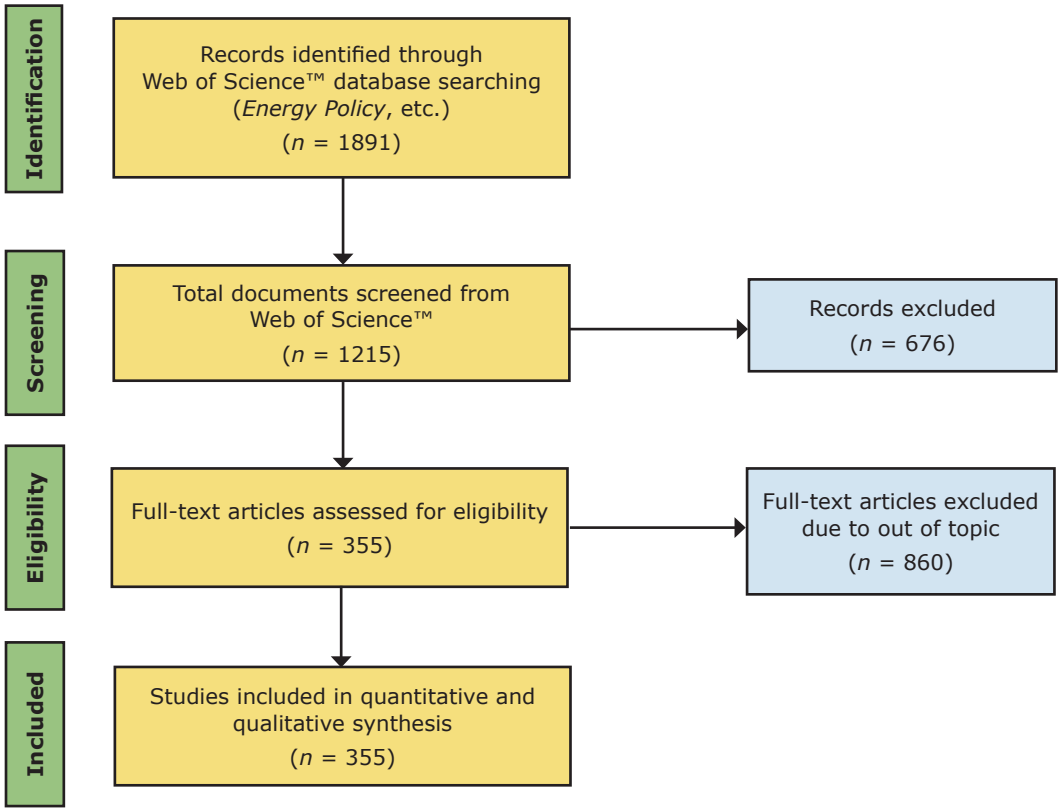

Fig. 1. PRISMA flowchart

3. Findings

3.1 Temporal Distribution of NEV Policy Literature

3.1.1 Temporal Distribution of NEV Policy Literature Globally

Figure 2 depicts the temporal distribution of articles in NEV policy research globally. The NEV policy research can be divided into the pre-development (2000–2010) and development period (2011–2021). The pre-development period had fewer publications because governments worldwide were initiating new policies for developing the NEV industry. For instance, China is the highest-performing country and it started supporting NEV industry development in 2001 by issuing a national high-tech R&D plan for NEV, which had a planning period from 2001 to 2005 (9). Thus, far fewer articles were published in this period (average: 2.625, 6% of sample). The development period (2011–2021) saw significant growth in papers (average: 32.4; 92.9% of sample) because NEV policies were promulgated globally. The average increase in publications shows that NEV policy research has increased with considerable growth in attention of researchers.

3.1.2 Temporal Distribution of NEV Policy Literature by Active Nations

Figure 3 shows the number of research articles are on the rise generally in three active countries. In terms of volume, China has the greatest number of publications followed by the USA and the UK. The USA had been leading research on NEV policy until 2013. From 2014 onwards, China has been publishing significantly on the topic. As China had a planning period from 2001 to 2005, their publications came after the implementation of policies. Other countries are not very active in this area. This might be because: (a) their carbon footprint is limited; (b) their transportation sector is completely fossil-fuel dependent; (c) countries may not have technology to develop energy vehicles.

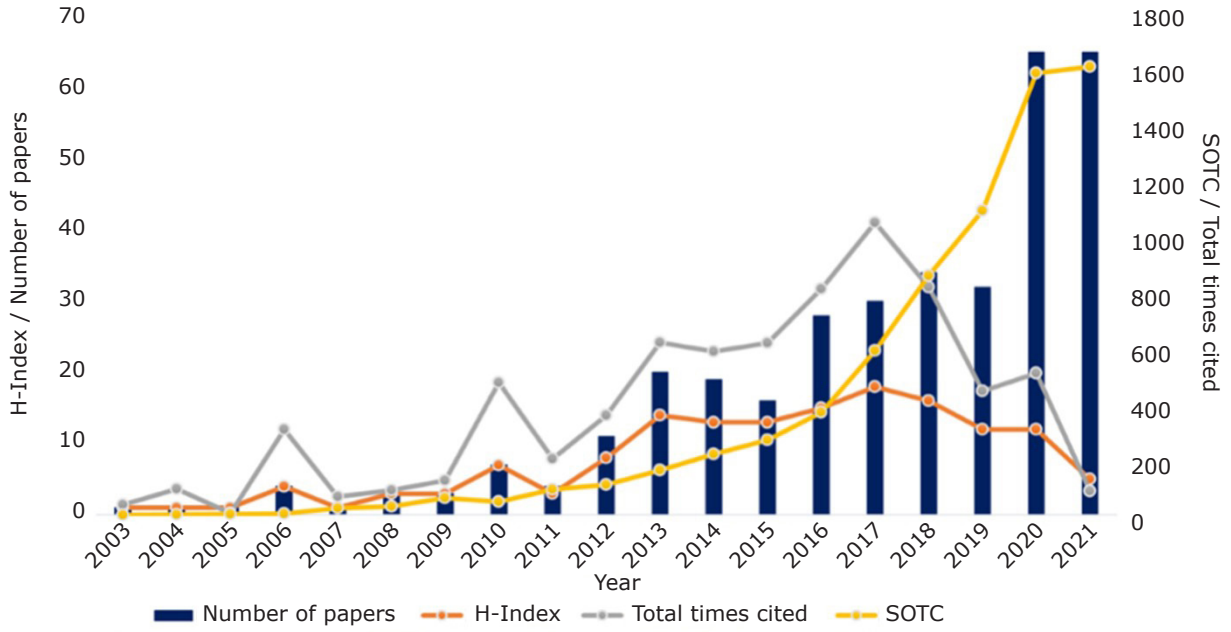

Fig. 2. Temporal distribution of NEV policy studies

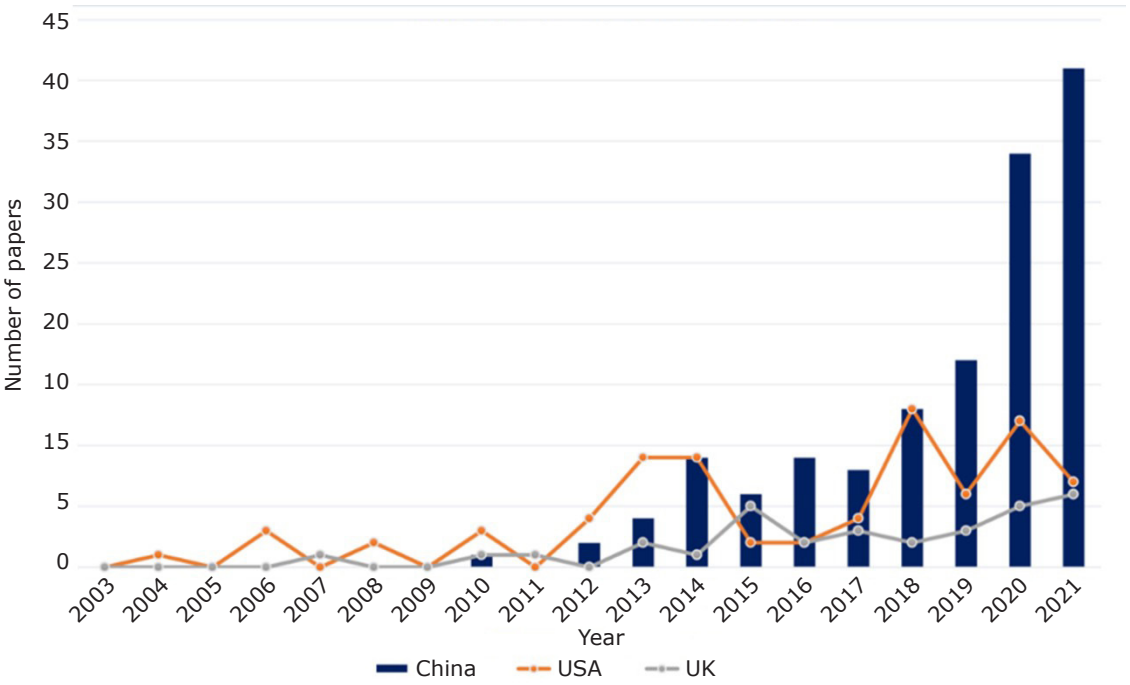

Fig. 3. Distribution of articles by active nations

3.2 Spatial Distribution of NEV Policy Literature

3.2.1 Distribution by Country/Region

The analysis shows that 56 countries have participated in NEV policy research, of which the top five are shown in **Table I**. China, the USA and the UK are the top three countries with the most publications. The USA, the UK and Germany are the three countries with the highest average citations per paper (ACP), which indicates that the level of research in these countries is higher. With the highest number of publications, China has the lowest ACP (10.09), indicating that China's research has less recognition.

Figure 4 represents the cooperation network among countries. The nodes and their sizes refer to countries and their importance. The links show

Table I Top Five Most Productive Countries for NEV Policy Research (Data to August 2021)

Rank	Country	Region	Quantity	Percentage	H-index	ACP[a]	Total link strength
1	China	East Asia	144	40.68	30	10.09	63
2	USA	North America	77	22.03	24	27.17	47
3	UK	Western Europe	32	9.04	15	26.69	35
4	Germany	Central Europe	26	7.35	13	23.58	27
5	The Netherlands	Western Europe	16	4.50	11	18.25	22

[a]ACP: average citations per paper

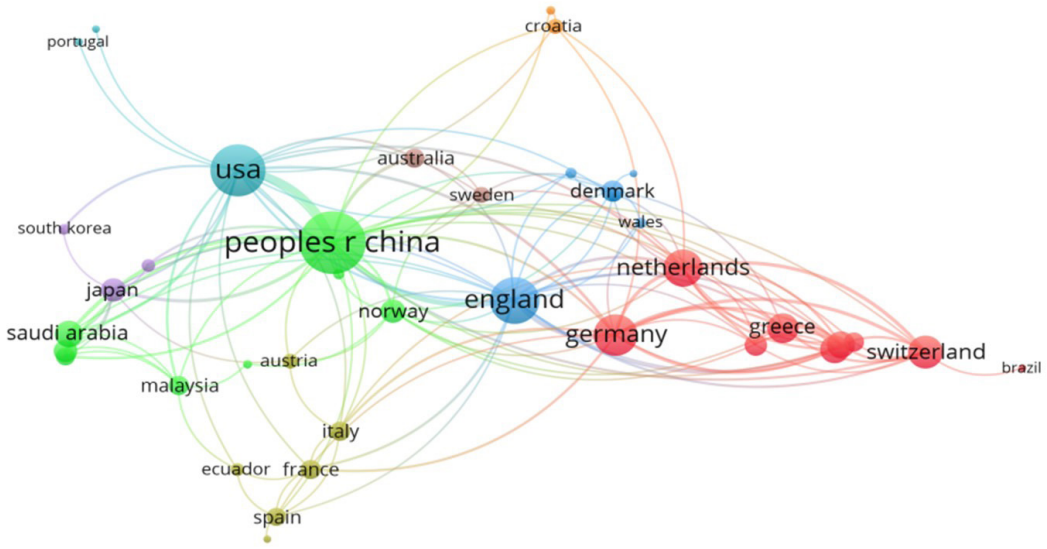

Fig. 4. Cooperation network of countries in NEV policy research (data to August 2021)

network strength: China and the USA are vital cooperators with more connections with other nations, advancing the automotive industry and largest markets in terms of production.

3.2.2 Distribution by Discipline

Table II provides the distribution of articles by subject categories. This helps understand the top five disciplines publishing research in the field. Using CiteSpace, 59 disciplines were identified from analysis, of which the top five disciplines are reported. The categories of Environmental Science and Ecology have the most publications (count: 169, 47.70%), followed by Environmental Studies (count: 130, 36.70%) and Energy and Fuels (count: 118, 33.40%). Higher centrality shows the significance and impact of that category. The analysis shows the Engineering discipline has the highest centrality (0.72), followed by Environmental Science and Technology (0.37). Cooperation among disciplines is vital to understand the significance of national-level policies, their formulation, implementation, effectiveness and whether their impact is aligned with the UN's Sustainable Development Goals (SDGs).

Table II Top Five Subject Categories on NEV Policy Research (Data to August 2021)

Rank	Subject category	Record count	Centrality	% of Total
1	Environmental Sciences and Ecology	169	0.37	47.70
2	Environmental Sciences	130	0.09	36.70
3	Energy and Fuels	118	0.21	33.40
4	Environmental Studies	112	0.12	31.63
5	Business and Economics	107	0.16	30.22

3.2.3 Distribution by Institutions

Table III provides the institutional distribution of articles. This institutional cooperation helps us Xpolicy research. A total of 504 institutions were acquired from the database, of which the top five with the most influential studies are reported. China's government policies are formulated solely to support the NEV industry to surpass developed countries in the automobile industry (22). Thus, China and the USA are leading players in NEV policy research. Tsinghua University has the highest number of publications at 23, followed by the Beijing Institute of Technology and China University of Mining and Technology with eight each.

Figure 5 depicts the institutional cooperation network analysis where authors from different institutions have co-authored NEV policy research. Tsinghua University and the Chinese Academy of Sciences have a strong cooperation network. Each colour embodies clusters. We found 12 clusters, of which red, green and blue are the largest, with 24, 21 and 20 nodes respectively.

The red cluster articles talk about the impact of policy documents on NEV promotion (23), dual credit policy, its flaws and its effects on consumer preferences and the production of ICEVs (24) and policy incentives to increase the consumer adoption of NEVs (25–27). The green cluster's content covers energy and climate policy (28), climate change policies, their impact on public health and transportation (29, 30) and the effectiveness of government subsidies (31). The blue cluster articles include the implementation of policy mixes to decarbonise electric cars (14, 32),

Table III Top Five Institutions on NEV Policy Research (Data to August 2021)

Rank	Institution	Country	Quantity	Total link strength	SOTC[a]	ACP[b]
1	Tsinghua University	China	23	9	671	29.17
2	Beijing Institute of Technology	China	8	4	361	45.13
3	China University of Mining and Technology	China	8	1	150	18.75
4	China University of Petroleum	China	7	3	228	32.57
5	Massachusetts Institute of Technology	USA	7	4	44	6.29

[a]SOTC: sum of times cited
[b]ACP: average citations per paper

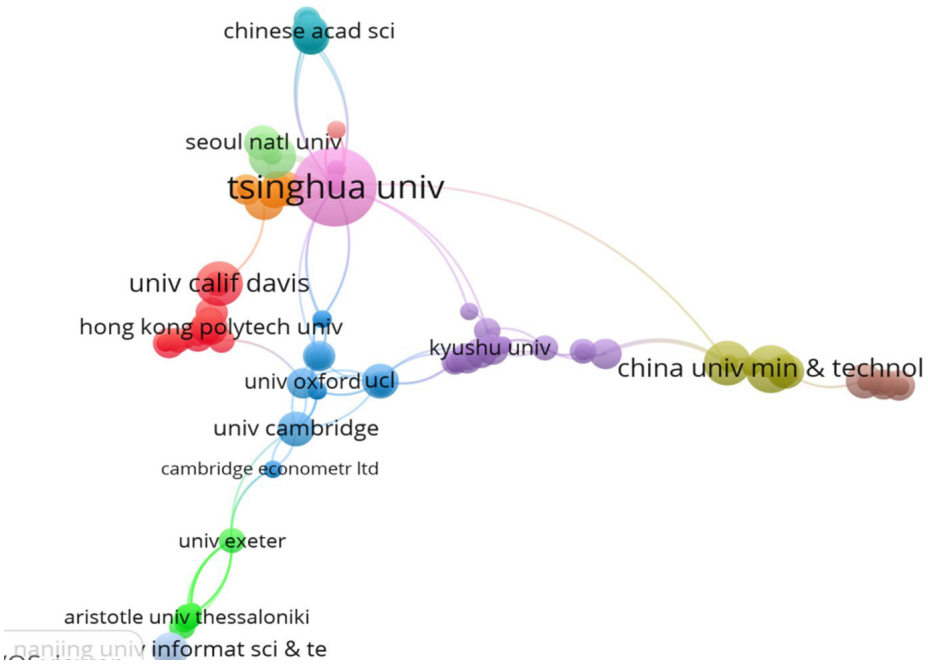

Fig. 5. Cooperation network of institutions in NEV policy research (data to August 2021)

pathways to achieve zero-carbon electricity (33), climate change policies and reduction of GHG emission in the transport sector (34–36). The total link strength between universities is relatively small, representing that institutions' cooperation is not very strong in NEV policy research. Strong cooperation between institutions can further develop NEVs policy research.

3.2.4 Distribution of Articles by Journals

Table IV provides the journal distribution of articles. *Energy Policy* (40 publications), *Sustainability* (26 publications) and *Journal of Cleaner Production* (23 publications) are the top three journals with the highest publications. The journals with the highest ACP and Journal Impact Factor are *Renewable and Sustainable Energy Reviews* (62.38, 14.98), *Energy Policy* (35.73, 6.142) and *Applied Energy* (29.00, 9.746). Most journals in the list are related to 'energy' as their main scope.

Figure 6 represents the journal cooperation network analysis which helps us identify the journal with the most substantial publication in NEV policy research. The node size shows the number of publications in these journals. For instance, the 'energy policy' node is largest,

Table IV Top Five Journals in NEV Policy Research (Data to August 2021)

Rank	Journal title	Quantity	Citations	ACP[a]	Citation Index	Impact Factor	H-index
1	*Energy Policy*	40	1429	35.73	SSCI/SCIE	6.142	217
2	*Sustainability*	26	208	8.00	SSCI/SCIE	3.251	85
3	*Journal of Cleaner Production*	23	515	22.39	SCIE	9.297	200
4	*Transportation Research Part A: Policy and Practice*	16	423	26.44	SCIE/SSCI	5.594	133
5	*Renewable and Sustainable Energy Reviews*	13	811	62.38	SCIE	14.982	295

[a]ACP: average citations per paper

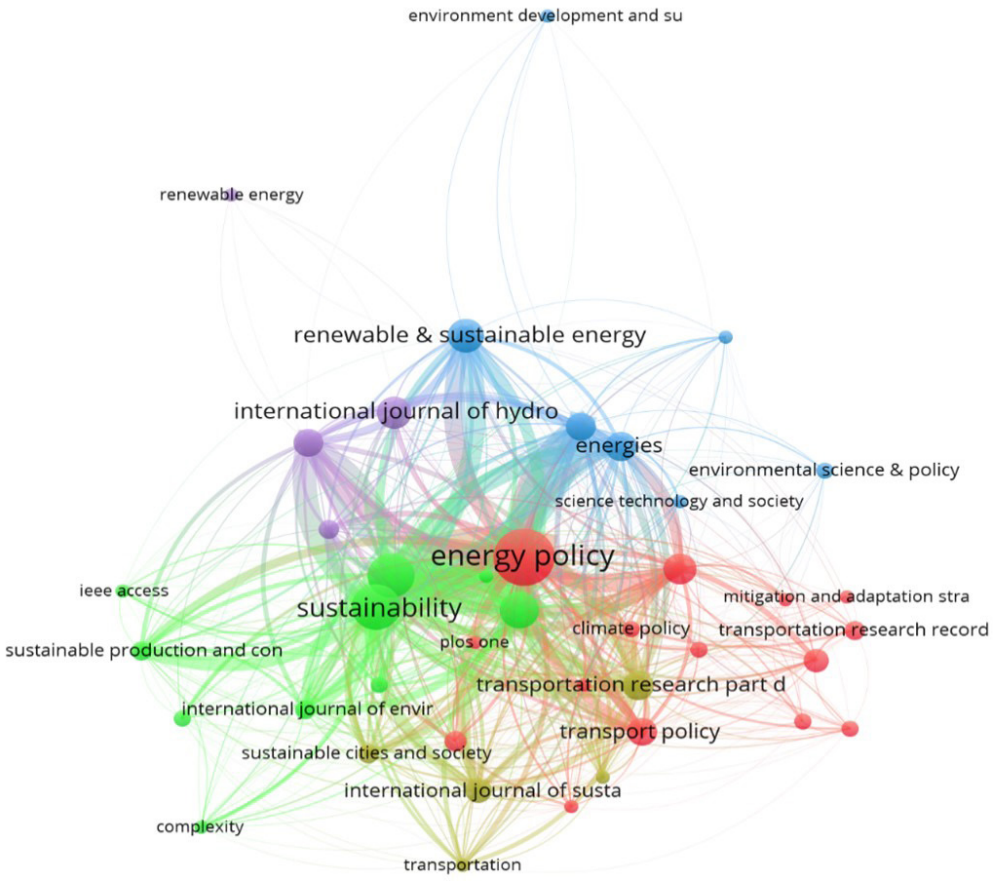

Fig. 6. Journal Cooperation Network Analysis (data to August 2021)

so **Table IV** represents the highest quantity of papers published in the *Energy Policy* journal, followed by *Sustainability*. Each cluster in **Figure 6** represents journals. With the help of VOSviewer, we acquired three clusters: the red cluster has 27 nodes, followed by green and blue. *Energy Policy*, *Sustainability* and *Renewable and Sustainable Energy Reviews* are the biggest nodes in red, green and blue clusters, respectively.

3.3 Network Visualisation for NEV Policy Research

3.3.1 Co-Authorship Analysis

The co-authorship network analysis is one of the most tangible and well-documented forms of scientific collaboration, depicting authors' collaborative activity in the field (37, 38). **Figure 7** depicts the co-authorship network analysis on NEV policy research.

The top 10 authors with the most publications are shown in **Table V**. Seven out of the 10 top authors are from China and four are from a single institute (Tsinghua University), which depicts that Chinese scholars have a more aggressive approach toward NEV policy research. The most cited author (Wang, Hewu) is also from Tsinghua University, with 233 citations and 77.33 ACP, followed by Hao, Han (158, 17.55) and Wang, Michael (152, 50.66). This analysis shows strong link strength in domestic scholars, but international cooperation still needs to improve.

3.3.2 Citation Analysis

Citation analysis is imperative for understanding the subject relations relative to different interests and paradigms (39). We used citation analysis to determine the research topics that gained much attention in NEV policy research. **Table VI** explains the top 10 papers based on the sum of times cited (SOTC). The table reveals the details of the SOTC, average citations per year (ACY), its title, authors, publishing journal and key contributions.

The most cited paper by Romm (40) has 175 SOTC and 10.75 ACY, followed by Kyriakopoulos and Arabatzis (41) with 155 SOTC and 25.83 ACY and Hanley *et al*. (42) with 141 SOTC and 35.25 ACY. Almost all highly cited papers talk about the development of NEVs and alternative energy systems, NEV policies, development, implementation and consequences of NEV policies.

3.3.3 Co-Citation Analysis of References and Journals

Co-citation analysis is a bibliometric method that helps us assess the document similarities and tracks the papers cited in the source articles (50, 51).

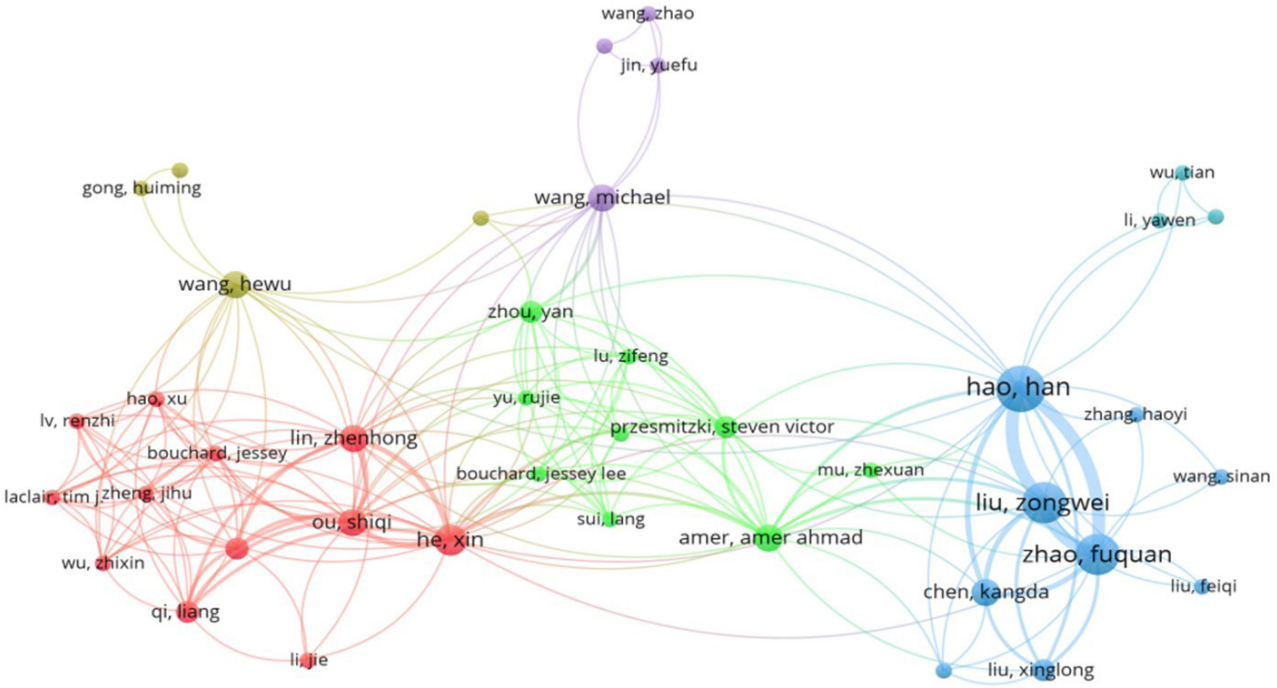

Fig. 7. Cooperative authors' network of NEV policy research (data to August 2021)

Table V Top 15 Authors with the Highest Number of Publications (Data to August 2021)

Rank	Authors	Organisation	Country	Links	Quantities	Citations	ACP[a]
1	Hao, Han	Tsinghua University	China	22	9	158	17.56
2	Liu, Zongwei	Tsinghua University	China	20	7	42	6
3	Zhao, Fuquan	Tsinghua University	China	20	7	42	6
4	He, Xin	Aramco Research Centers	USA	13	4	87	21.75
5	Long, Ruyin	China University of Mining and Technology	China	3	4	111	27.75
6	Amer, Amer Ahmad	R&D Center, Saudi Aramco	Saudi Arabia	12	3	12	4
7	Chen, Kangda	Tsinghua University	China	10	3	21	7
8	Li, Jizi	Nanchang University	China	6	3	33	11
9	Li, Wenbo	China University of Mining and Technology	China	3	3	106	35.33
10	Lin, Zhenhong	Oak Ridge National Laboratory	USA	9	3	83	27.67

[a]ACP: average citations per paper

Table VI Top 10 Papers with the Highest Number of Citations (Data to August 2021)

Rank	SOTC[a]	ACY[b]	Title	Reference	Journal	Key contribution
1	172	10.75	'The Car and Fuel of the Future'	(40)	*Energy Policy*	The paper gave a review of the technical literature on AFVs. Romm explained that: (i) HEVs are the forthcoming future cars because of their vital role in decreasing GHG emissions with no serious macroeconomic consequences; (ii) in the long term, HEVs will need to be substituted by zero-carbon vehicles, which compel tremendous technological advancement efforts and concentrated government policies to change the entire gasoline infrastructure
2	155	25.83	'Electrical Energy Storage Systems in Electricity Generation: Energy Policies, Innovative Technologies, and Regulatory Regimes'	(41)	*Renewable and Sustainable Energy Reviews*	This paper studied the pathways to electrical energy storage systems, their must-have technologies, technological development, technological implementation and a wide spectrum of energy policies
3	141	35.25	'The Role of Hydrogen in Low Carbon Energy Futures – A Review of Existing Perspectives'	(42)	*Renewable and Sustainable Energy Reviews*	This paper evaluated the emergence of hydrogen over other integrated energy system models to accomplish the decarbonised energy system. Hanley further studied the drivers and policy scenarios on global, multi-regional and national levels to weigh the uncertainty and complexity surrounding hydrogen and suggested policymakers make informed decisions
4	122	11.09	'Battery Electric Vehicles, Hydrogen Fuel Cells and Biofuels. Which Will Be the Winner?'	(43)	*Energy & Environmental Science*	This paper reviewed seven high-profile studies which compare the different NEVs (PHEVs, HEVs, BEVs). They concluded that alternative fuels are necessary to meet the long-term policy targets, but their development and uptake require strong policies. Moreover, BEVs and HEVs are expected to play a vital role compared to PHEVs, which can be constrained because of lack of sustainable fuels

Table VI Continued

Rank	SOTC[a]	ACY[b]	Title	Reference	Journal	Key contribution
5	119	9.917	'Green Drivers or Free Riders? An Analysis of Tax Rebates for Hybrid Vehicles'	(44)	*Journal of Environmental Economics and Management*	This paper studied the impact of tax rebates and their cost-effectiveness for HEVs and evidenced that tax rebates played a significant role in increasing the market share of HEVs. However, these tax incentives are not effective in switching consumers' preferences because of their short-term benefits. Governments need to explore cost-effective alternative policy options
6	117	9.75	'Analysis of Policies to Reduce Oil Consumption and Greenhouse-Gas Emissions from the US Transportation Sector'	(45)	*Energy Policy*	This paper studies the policy scenarios (fuel taxes, increased fuel economy standards, NEV purchase policies and NEV purchase tax credits) and their impact on the reduction of GHG emissions and consumption of oil
7	101	20.2	'Progress of Chinese Electric Vehicles Industrialization in 2015: A Review'	(46)	*Applied Energy*	This paper studies the international trend in technological development and industrialisation of NEVs with the help of the triple-perspective method. They concluded the main industrialisation paths are: (i) market penetration through state policies; (ii) extended range PHEVs; (iii) commercialisation of micro-electric cars; and (iv) installing charging infrastructure
8	101	11.22	'New Energy Vehicles in China: Policies, Demonstration, and Progress'	(47)	*Mitigation and Adaptation Strategies for Global Change*	This paper studied China's Thousands of Vehicles, Tens of Cities (TVTC) Program and its impact on R&D, production and commercialisation of NEVs and found that the programme is lagging behind the original plan, but policy stimulation has increased NEVs production intensely
9	99	14.14	'Plug-in Electric Vehicle Market Penetration and Incentives: A Global Review'	(48)	*Mitigation and Adaptation Strategies for Global Change*	This paper reviews the plug-in electric vehicle (PEV) market globally. It claims that national and regional level incentives and government policies are essential to accelerate market adoption and consumer acceptance in the PEV market
10	99	12.37	'Long-Term Transport Energy Demand and Climate Policy: Alternative Visions on Transport Decarbonization in Energy-Economy Models'	(49)	*Energy*	This paper compared long-term transport energy demand and projected CO_2 emissions with the help of five large-scale energy economy model responses to three climate change policies. The evidence shows that before 2060, the transport sector will be the most challenging sector to decarbonise. The complete decarbonisation of the transport sector solely depends upon using advanced vehicle technologies and carbon-free energy sources

[a]SOTC: sum of times cited
[b]ACY: Average citations per year

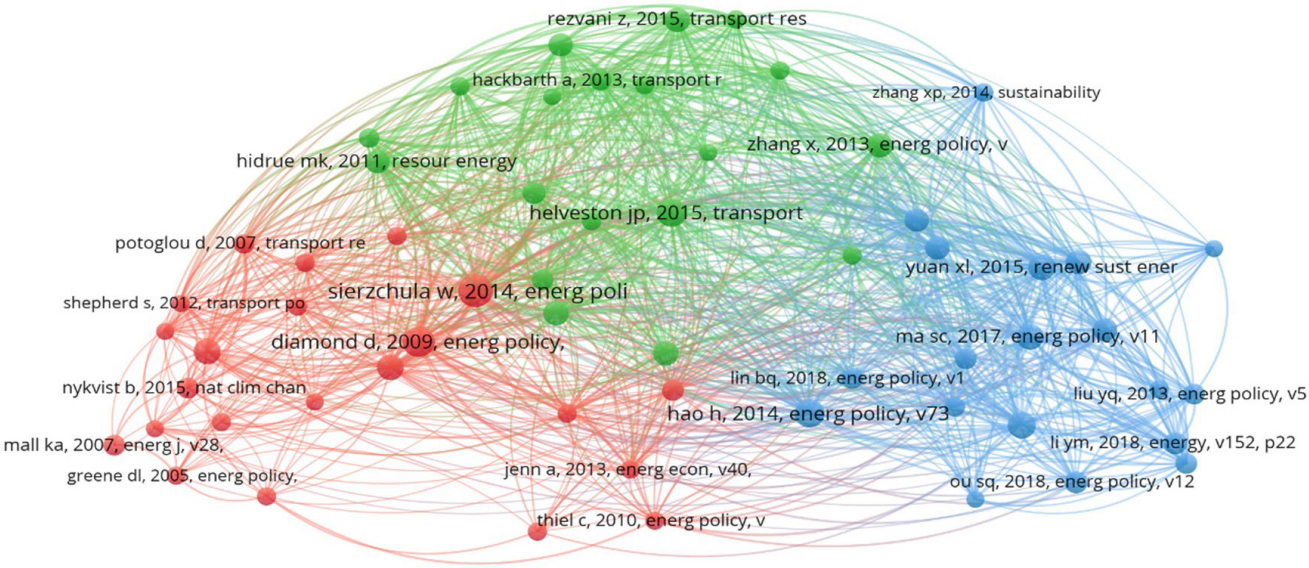

Fig. 8. Reference co-citation network of NEV policy research (data to August 2021)

The clusters created through co-citation analysis share a common theme and map the structure of specialised research areas. Many scholars (3, 21, 52) use this method. Following them, we use reference and journal co-citation analysis to identify the knowledge base and the carriers of NEV policy research.

The reference co-citation depicts the relationship between documents. If a group of documents cites one previous article together, then that group of documents has a strong link and similarity in their research directions (50, 53). **Figure 8** depicts the reference co-citation network on NEV policy research. The red, green and blue clusters have 24, 19 and 17 items. We analysed each item and assigned the cluster's theme based on its research gap and contribution.

The central theme of the red cluster is 'incentive policies and consumer adoption of NEVs'. The studies primarily discuss different incentive policies initiated by governments worldwide to motivate and encourage consumers to switch to green and advanced technologies in vehicles. For instance, Sierzchula *et al*. (54) (36 co-citations) studied the impact of government policies and socioeconomic factors on electric vehicle adoption. They claimed that financial incentives to consumers, NEV charging infrastructure and domestic NEV production facilities encourage consumers to adopt NEVs and increase the NEV market share. Diamond *et al*. (55) (33 co-citations) also examined the impact of government incentive policies on the adoption of HEVs. They found that gasoline prices play a vital role in the adoption of HEVs because gasoline prices encourage consumers to purchase fuel-efficient cars, which stimulates the induction of NEV technologies in the market. Gallagher and Muehlegger (56) (22 co-citations) evaluated the impact and effectiveness of federal, state and local government incentive policies (sales tax waivers, income tax credits and non-tax incentives) on an elevation of consumer adoption of HEVs. They found that generosity and type of tax incentive play a vital role and sales tax waivers boost the HEV adoption and sales by tenfold compared to income tax credits. Additionally, the increase in fuel prices encourages consumers to adopt greener and more energy-efficient technologies.

The green cluster's central theme is 'NEV policy formation and evaluation'. Hao *et al*. (57) (26 co-citations) studied and explained the foundations and logic of China's electric vehicle subsidy policy and evaluated the impact of this policy on the diffusion of the NEV market based on ownership cost analysis of battery electric vehicles (BEVs). They explained that Phase I of the policy (before 2015) focused on battery capacity-based subsidy standards and reducing the ownership cost of BEVs. However, Phase II of the policy focused on electric range-based subsidy standards by decreasing the focus on the cost-effectiveness of BEVs. Albeit in Phase II, BEVs remained cost-effective because of the decrease in the manufacturing cost of BEVs.

Zhang and Bai (58) (25 co-citations) analysed the systematic link between the NEV policies and how these policies enhance NEV development, provide support to key players to cope with challenges and heighten NEV adoption. The regional and provincial

governments coordinate to resolve issues within their regions and local government plays a vital role in implementing national and provincial policies and coping with challenges like the development of the local economy and traffic congestion. Yuan *et al*. (59) (23 co-citations) provided an inclusive and analytical review of the NEV policy framework. They explained that the NEV industry had been given a top priority in the Chinese automotive sector, formulation and guidance of policies have an influential role in the growth of the NEV industry. However, technological innovation, supply chain framework and socioeconomic factors are critical challenges in the industry. This industry still needs preferential policies and infrastructure to adapt to the emergent demand for NEVs.

The third cluster's central theme is 'consumer attitude, preference and intention to NEV adoption'. For instance, Helveston *et al*. (60) (26 co-citations) modelled consumers' preferences for technologies of ICEVs, HEVs, plug-in hybrid electric vehicles (PHEVs) and BEVs in the USA and China. The findings suggest that US and Chinese consumers prefer gasoline vehicle technology and Chinese consumers are willing to pay more for BEV technology than US consumers. Additionally, excluding the subsidies effect, Chinese consumers prefer to adopt BEVs and mid-range PHEVs. In contrast, US consumers prefer to adopt low-range PHEVs, which leads to early adoption of BEVs in China. Early adoption of BEVs might increase global incentives to the NEV industry and decrease GHG emissions.

Jansson and Rezvani (61) (20 co-citations) provides a critical review of studies related to consumer preferences toward NEV adoption and study the drivers and barriers of NEV adoption. Moreover, they explained the theoretical perspective to understand the intentions and behaviour of consumers towards NEV adoption. Zhang *et al*. (62) (20 co-citations) studied the purchasing behaviours of NEVs in China and identified government policies' motivating factors and effects on purchasing behaviour. The findings show that the performance of NEVs, financial benefits and environmental awareness are vital in encouraging consumers' NEV purchases.

Journal co-citation was initially utilised by McCain (63) and revealed that this analysis constructs comprehensible and precise results for academicians to identify the structure and relationship of an academic field in which journals are the main communication channel. **Figure 9** presents the journal co-citation network. By setting the minimum number of co-citations criteria to 10, we acquired 166 journals categorised into three clusters: red, green and blue, with 89, 60 and 17 items. The red cluster's prominent journals are *Energy Policy* (co-citations 1592), *Journal of Cleaner Production* (co-citations 453) and *Renewable and Sustainable Energy Reviews* (co-citations 397). The scope of journals mainly revolves around Energy Resources and Environment.

The green cluster's prominent journals are *Transportation Research Part A: Policy and Practice* (co-citations 471), *Transportation Research Part D: Transport and Environment* (co-citations 466) and *Energy Economics* (co-citations 211). The scope of journals is mainly on Policy Analysis, Environmental Impact on Transportation and Strategic Transport Policy.

The blue cluster's main journals are *European Journal of Operational Research* (co-citations

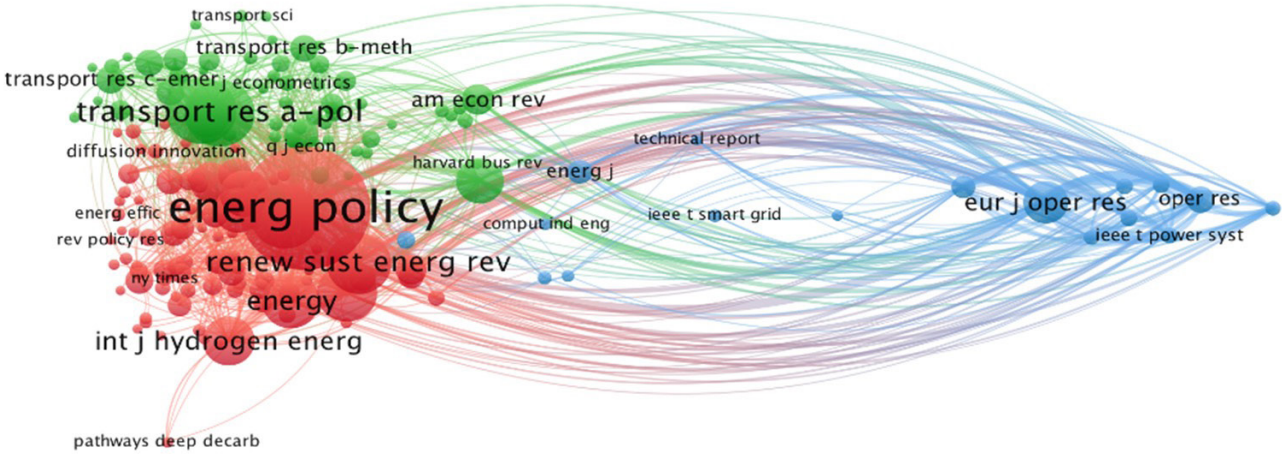

Fig. 9. Journal co-citation network of NEV policy research (data to August 2021)

195), *Operational Research – An International Journal* (co-citations 76), *The Energy Journal* (co-citations 65) and *Management Science* (co-citations 57). The research theme is related to Energy Conservation, Decision-Making and Management. In terms of co-citations, *Energy Policy*, *Transportation Research Part A: Policy and Practice* and *Transportation Research Part D: Transport and Environment* are journals with the highest number of co-citations.

3.4 Evolutionary Path of NEV Policy Research

3.4.1 Keyword Co-Occurrence Analysis

Keywords of research articles are imperative because scholars decide on keywords to correspond to the core content of the article. We employ the keyword co-occurrence analysis to explore the evolutionary path of NEV policy research. **Table VII** epitomises the top 10 keywords that appeared in NEV policy research. Three main keywords are: (a) 'electric vehicles' because it is used for all kinds of NEVs; (b) 'adoption' because consumers' willingness to adopt NEVs is essential in NEV industry and policy development; (c) 'policy' because formulation, implementation, effectiveness and repercussions of policies are significant for NEV industry development.

Figure 10 illustrates the network of keyword co-occurrence in NEV policy research. By setting the minimum number of co-occurrences to five, we attained 134 keywords catalogued into four clusters: red, green blue and yellow with 53, 33, 31 and 17 items.

Table VII Top 10 Keywords of NEV Policy Research (Data to August 2021)

Rank	Keyword(s)	Occurrences	Total link strength
1	Electric vehicles	153	345
2	Adoption	56	168
3	Policy	56	131
4	Incentives	44	119
5	Impact	38	89
6	China	37	85
7	CO_2 emissions	62	116
8	Energy	32	53
9	Transport	23	44
10	Renewable energy	20	42

The keywords with highest co-occurrences in the red cluster are 'emissions' (34 co-occurrences), 'energy' (32 co-occurrences), 'CO_2 emissions' (28 co-occurrences), 'consumption' (27 co-occurrences) and 'impacts' (27 co-occurrences). The hotspot of red cluster keywords is the impact of NEV policies, incentives and recommendations on CO_2 emissions. Anwar *et al*. (64) studied how public and private investments are associated in the transport sector and their effect on carbon emissions. They endorsed cooperation between policymakers and industry to accomplish the decarbonisation goal and the industry should transit towards green energy sources to curtail CO_2 emissions. Zhang *et al*. (65) implied that NEVs play a noteworthy role in reducing CO_2 emissions, so comprehensive subsidy strategies will enhance the promotion of these vehicles and benefit from their green effect. Kok (66) studied the impact of tax incentive policies on CO_2 effectiveness for low-carbon vehicles and found that tax incentive policies motivate consumers to buy more energy-efficient vehicles. Zheng *et al*. (36) provided the integrated policy mix to achieve the 2030 GHG emission goal by promoting the use of energy-efficient vehicles, endorsing alternative fuel options, decreasing ICEVs and improving fuel economy.

The keywords with highest co-occurrences in the green cluster are 'incentives' (44 co-occurrences), 'China' (37 co-occurrences), 'model' (23 co-occurrences), 'demand' (22 co-occurrences) and 'preferences' (19 co-occurrences). The studies using these keywords in the green cluster mainly discuss policy incentives, promotion mechanisms and their effect on NEV industrial development, consumer preferences and purchase intentions. Dong and Zheng (67) explained that the dual credit policy positively affects the total factor productivity of NEVs through innovation in technology, improvement in corporate reputation and managers' autonomy. Liu *et al*. (68) studied the impact of government incentives on NEV adoption and provided solid evidence that subsidies, charging infrastructure and increases in fuel prices promote the adoption of electric vehicles. Gong *et al*. (69) developed a discrete choice model to observe consumers' preferences associated with NEV attributes and government incentives. The cost of NEVs is the most influential attribute, followed by reductions in energy bills and parking tolls, which help to penetrate the NEV market.

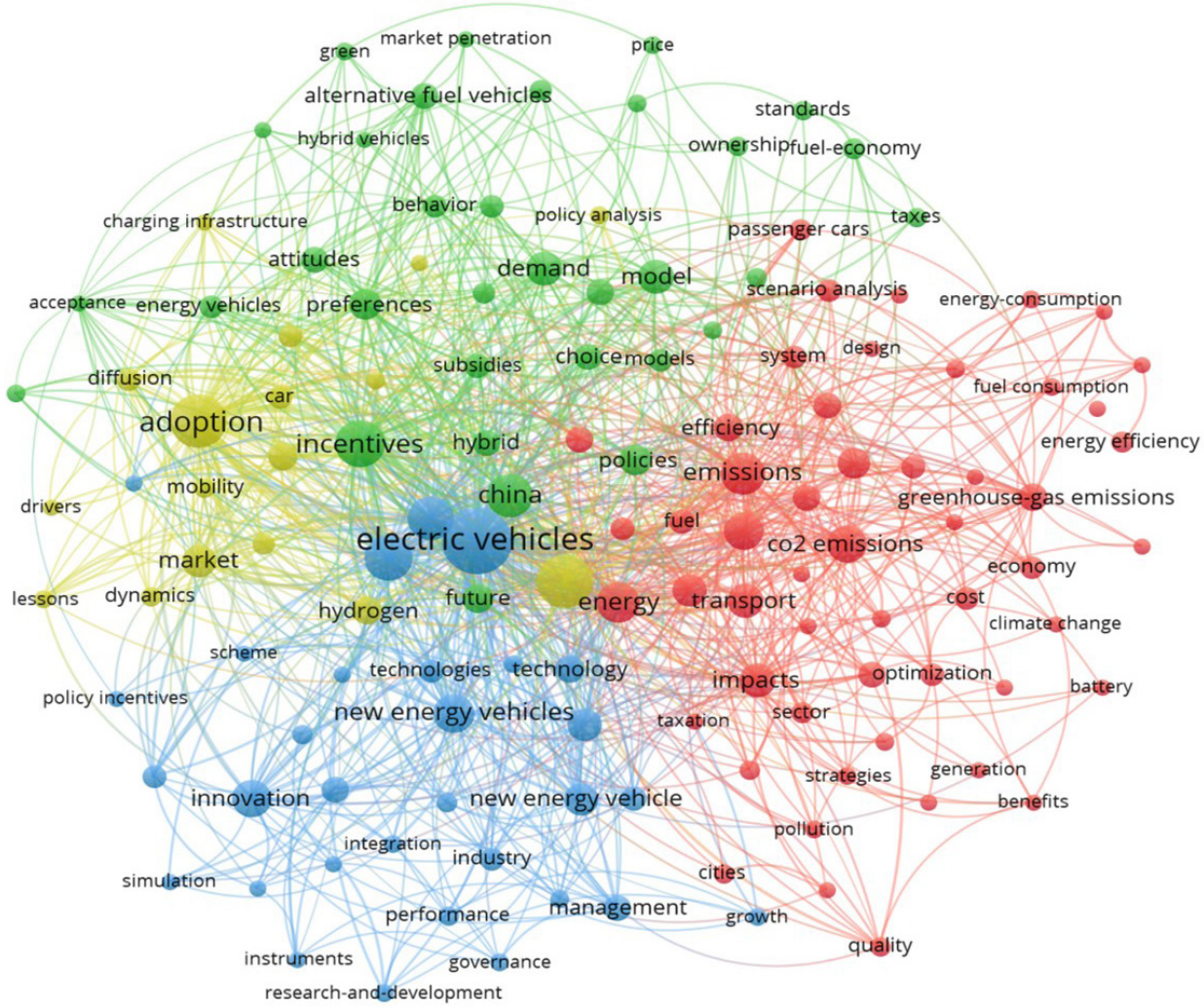

Fig. 10. Keyword co-occurrence network of NEV policy research (data to August 2021)

The keywords with the highest co-occurrences in the blue cluster are 'electric vehicles' (85 co-occurrences), 'impact' (38 co-occurrences), 'new energy vehicles' (29 co-occurrences) and 'innovation' (27 co-occurrences). The studies in this cluster talk about all kinds of electric vehicles.

The hotspot of studies is the integration of EV policies, innovation-diffusion simulation and sustainable development of the EV market. Wolf *et al*. (70) provided an agent-based model (InnoMind) to perform innovation-diffusion simulation on policy interventions and social influence on consumer preferences and decision-making. They employ cognitive theories and empirical data to analyse scenarios. The results indicate that policies tailored to the heterogenous needs of consumers, an exclusive zone for electric vehicles and bicycle users' shift to EVs are three critical scenarios that can change minds and boost NEV diffusion. Lopez-Arboleda *et al*. (71) provided a systematic approach to integrate the sustainability dimension, EV market dynamics and consumer behaviours toward EV adoption.

The main keywords with the highest co-occurrences in the yellow cluster are 'adoption' (56 co-occurrences), 'policy' (56 co-occurrences) and 'market' (21 co-occurrences). The hotspot of research in this cluster is drivers of electric vehicle adoption, technology awareness and related policy measures. Some scholars have studied the policy incentives and vital factors which boost EV adoption. Higueras-Castillo *et al*. (72) determined the factors which predict the consumers' purchase intentions of electric vehicles and evidenced that range, reliability and incentives are the most vital factors. Zimm (73) evaluated the variation in policy diffusion and its effect on EV diffusion by identifying the mechanisms related to new technology, its domestic and international adoption and implementation, keeping in mind the country's goal towards EV diffusion. Mohammed *et al*. (74) provided the Firm Adoption of Sustainable

Technologies (FAST) framework and found the crucial enablers (environmental profits, strategic and economic benefits and efficiency) and barriers (organisation policies, lack of knowledge and operational blockades) to EV fleet adoption.

3.4.2 Research Frontier Analysis

To identify the research frontiers of NEV policy study *via* keywords co-occurrence distribution, we acquired a keywords cluster map and keyword timeline view of NEV policy studies. The keyword cluster map was obtained from CiteSpace, as depicted in **Figure 11**. Following Luo *et al*. and Wang *et al*. (3, 75), we used three methods to acquire NEV policy research clusters to develop the knowledge base for the field. We used latent semantic indexing (LSI), log-likelihood ratio (LLR) and mutual information (MI) methods to acquire these clusters. We used LSI instead of term frequency-inverse document frequency (TF-IDF) methods because Zhang *et al*. (76) compared both methods and claimed that the LSI method has better semantic quality and better categorisation performance. We identified 12 clusters and their relative importance (the largest cluster is #0 and the smallest cluster #21). The total number of publications in the cluster determines the size of a cluster. The largest cluster #0 'dual-credit policy' has 148 publications, followed by #1 'new energy vehicle industry' with 135 and #2 'hydrogen infrastructure' with 44 publications.

Table VIII shows the details of all the clusters acquired from CiteSpace; the silhouette value of all the clusters is greater than 0.65, representing that all the clusters are meaningful and vital (75, 77). Some clusters overlap in the data because some studies simultaneously belong to more than one cluster.

The keyword timeline effectively ascertains emerging trends and evaluates research pathways over time by summarising the documents succinctly and accurately. This technique aids scholars in gaining deeper insights into the development of the research field (78). In the keyword timeline view depicted in **Figure 12**, the cross represents the frequency of keywords; the larger the cross, the larger the frequency. The nodes and their connection denote the keyword and their co-occurrence relationship. The timeline is depicted on a horizontal axis. There are five timelines in **Figure 12**, which represent the research directions in NEV policy research: the efficiency of NEV policies and industrial development; consumer preferences and NEV adoption; efficiency and cost of AFVs; climate policy and CO_2 emission; hydrogen energy and fuel cell vehicles. These timelines are complex because of the integration of vehicle-related systems, which denotes that research directions involve multiple research domains and disciplines.

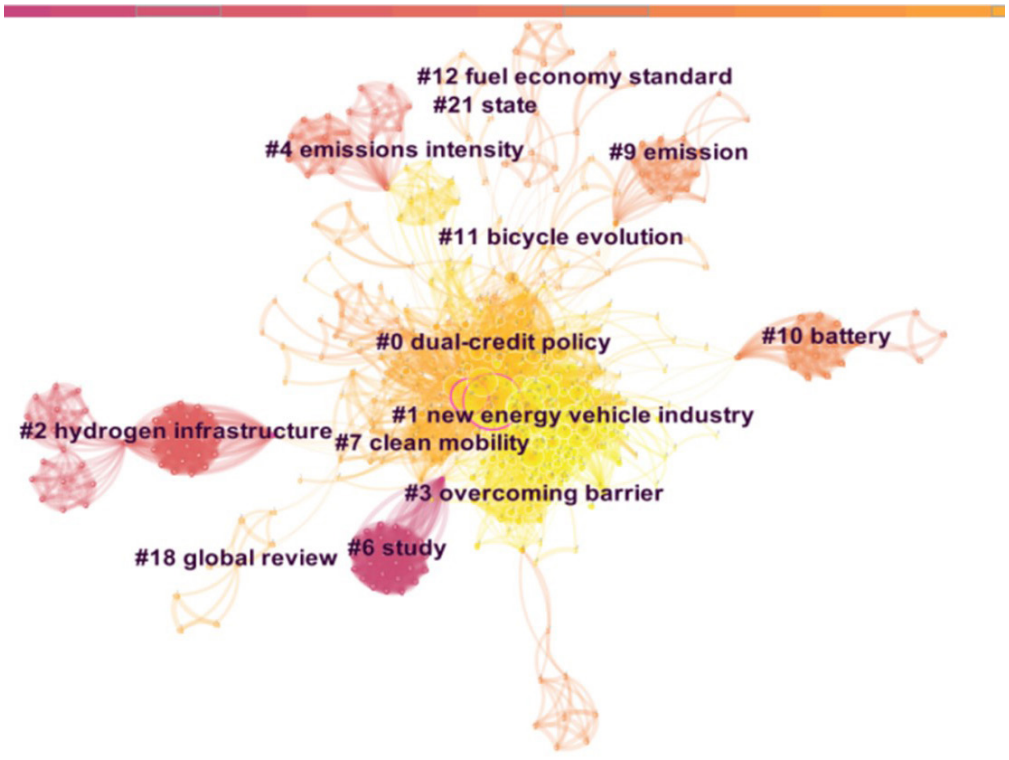

Fig. 11. Clusters of NEV policy research (data to August 2021)

Table VIII Clusters and Their Terms in NEV Policy Research (Data to August 2021)

Cluster	Size	Silhouette	Cite year	Label (LLR)	Label (LSI)	Label (MI)
0	148	0.689	2008	Dual-credit policy	Electric vehicle	Vehicle automation policymaking
1	135	0.866	2014	New energy vehicle industry	New energy vehicle	Vehicle automation policymaking
2	44	0.999	2002	Hydrogen infrastructure	Transport sector	Electric vehicle
3	41	0.934	2013	Overcoming barrier	Electric vehicle	Public support
4	28	0.997	2004	Emissions intensity	Evidence	Electric vehicle diffusion
6	26	0.997	1996	Study	Fuel efficiency	New energy vehicle
7	26	0.972	2009	Clean mobility	Clean mobility	Electric vehicle transition
10	17	1	2007	Battery	Battery electric vehicles	Electric vehicle
9	17	1	2007	Emission	Private car taxation policy	Electric vehicle
11	16	0.983	2008	Bicycle evolution	Bicycle evolution	Electric vehicle
12	15	0.992	2007	Fuel economy standard	Fuel economy standard	Electric vehicle
18	8	0.995	2011	Global review	Plug-in electric vehicle	Electric vehicle
21	6	1	2011	State	Environmental sustainability	Electric vehicle

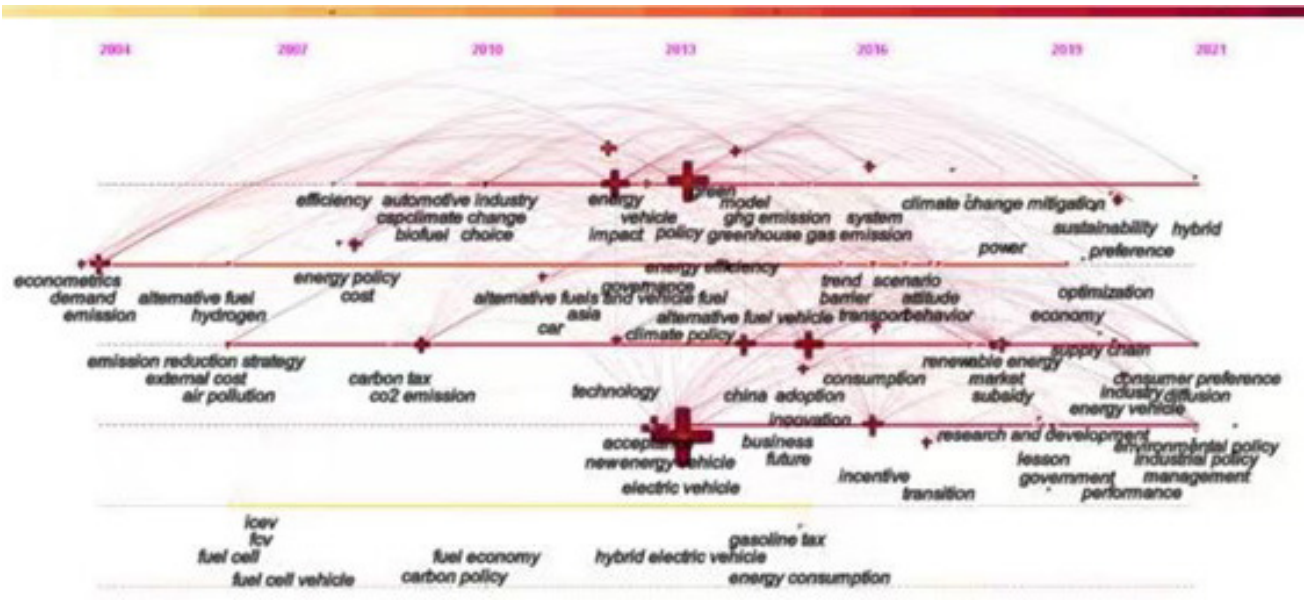

Fig. 12. Timeline view of keywords in NEV policy research

The knowledge base of NEV policy research can be divided into five research fronts: (a) efficiency of NEV policy and industrial development; (b) consumer preferences and NEV adoption; (c) efficiency and cost of AFVs; (d) hydrogen energy and fuel cell vehicles; and (e) climate policy and CO_2 emissions. The knowledge base is presented in **Figure 13**. The research direction of efficiency of NEV policy and industrial development covers the topics of electric vehicle market dynamics, policy evolution and framework, innovation-diffusion simulations and R&D of NEV technology. The

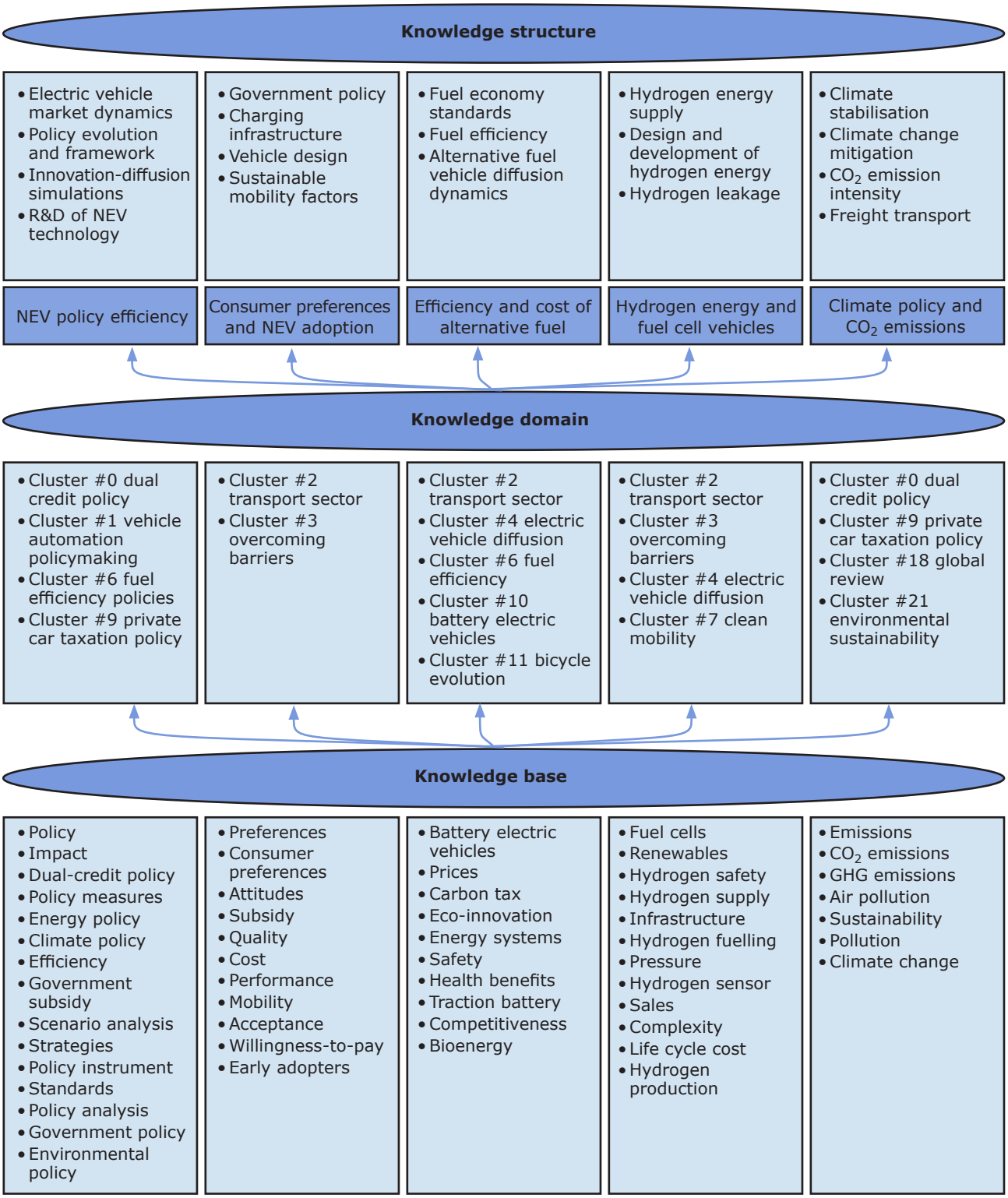

Fig. 13. Knowledge roadmap of NEV policy research

research direction of consumer preferences and NEV adoption includes the topics of government policy attributes, charging infrastructure development, vehicle design and sustainable mobility factors. The research direction on the efficiency and cost of AFVs covers fuel economy standards, fuel efficiency and AFV diffusion dynamics. The research direction of hydrogen energy and fuel cell vehicles covers hydrogen energy supply, design and deployment of the hydrogen energy supply chain and hydrogen leakage. The research direction of climate policy and CO_2 emissions includes the topics of climate stabilisation, climate change mitigation, CO_2 emission intensity and freight transport.

4. Discussion and Future Directions

The widespread use of electric vehicles can reduce GHG emissions and improve local environments by reducing tailpipe emissions. While they may have unexpected consequences on world supply chains, they are recognised as a core component of local and global decarbonisation policies.

The result of this study shows that NEV policy has been studied sporadically by scholars with the lone aim of understanding the impact of different NEV policies on performance in the NEV industry. This research investigates the evolution of NEV policy research and current research dynamics from different viewpoints and delivers significant contributions.

First, this paper carries out preliminary analysis of pre-development (2000–2010) and development period (2011–2021) to trace the increase in NEV policy research papers, identify key countries, authors and institutions. The number of publications has increased rapidly in the late development period. The annual growth of NEV policy papers in the pre-development period is 2.625 articles per year, while the development period has 32.4 papers per year. China is a most productive country in terms of publications, but the USA, the UK and Germany surpass China in terms of paper citations. Second, the co-citation analysis represents the reference co-citation (**Figure 8**) and journal co-citation analysis (**Figure 9**) which reveal the connection between two research papers, authors, institutions or countries that can acquaint researchers with noteworthy collaborations, research trends and topic or keyword evolution. This analysis helps us to identify three distinct clusters which were themed as: (a) incentive policies and consumer adoption of NEVs; (b) NEV policy formation and evaluation; and (c) consumer attitude, preference and intention to NEV adoption.

Third, to understand the evolutionary path of NEV policy research, keyword co-occurrence analysis (**Figure 10**) is presented, which helps us identify four different clusters. Each cluster has different keywords with occurrences and hotspots which represent the general theme or topic of research papers. Through keyword co-occurrence analysis, we also performed research frontier analysis (**Figure 11**) and keyword timeline view (**Figure 12**). The clusters represent research fronts of NEV policy research and keywords that were used in different time periods. Fourth, the development of knowledge structure (**Figure 13**) with the help of research frontier analysis (cluster map) helps us understand the main themes of the topic and which clusters and keywords relate to that theme. Fifth, the VOSviewer and CiteSpace software deliver detailed graphical analyses which are quick and easy to understand. Finally, the comprehensive bibliometric review of NEV policy research has helped us identify and propose the prospective research questions related to each identified theme as shown in **Table IX**.

Table IX Future Research Directions

Rank	Research Stream		Research Questions	Reference
1	The efficiency of NEV policy and industrial development	1	What is the evaluation mechanism of NEV credit transactions (bidding, pricing and targeted transactions)?	(79)
		2	What is the fundamental policy adoption mechanism for local financial subsidy policy? Do other relevant industry policy adoption mechanisms help enhance broader policy practices in the NEV industry?	(80)
		3	What is the evaluation path of NEV supporting policies of typical provinces and how do these policies match the central governments' policies?	(81)
2	Consumer preferences and NEV adoption	4	What is the impact of car-sharing experiences on the intention to use NEVs?	(82)
		5	What are cooperation methods between car-sharing companies and governments and which methods are effective for developing NEVs?	(82)
		6	What are the effects of consumers' perception of usefulness and ease of use on purchase behavior? Whether the consumers' perception is different towards different products of NEVs (types and brands)?	(83)

Table IX Continued

Rank	Research Stream		Research Questions	Reference
		7	Do consumers' preferences affect the key operational decisions of manufacturers and retailers of NEVs?	(24)
		8	Whether promotion policy of NEVs incorporate the design and optimisation of credit mechanisms?	(24)
3	Efficiency and cost of AFV	9	Which vehicle attributes (weight, engine capacity, purpose of use) have more tax and subsidy benefits?	(84)
		10	Which car and fuel type will have a significant market share and proportion of particulate matter emission by using exhaust and non-exhaust options?	(84)
4	Hydrogen energy and fuel cell vehicle	11	What are private costs, social costs, environmental externalities, resource constraints of hydrogen supply chains and fuel cell technologies?	(85)
		12	What are cheaper and cost-effective substrates and materials for reactor design?	(86)
		13	Whether metabolic, genetic engineering, bioreactor design and integration of two or more biohydrogen technologies improve the H_2 yield and production costs?	(86)
5	Climate policy and CO_2 emissions	14	What is the impact of consumers' green awareness on their purchasing decisions, manufacturers' profit, retailers' profit, remanufacturers' profits and the profits of the entire closed-loop supply chain?	(87)
		15	What is the automobile manufacturer's optimal response strategy in case a carbon price is distributed?	(87)

5. Conclusion

Policy incentives and other support are critical to accelerating NEV adoption and many countries are considering bans on the sale of ICEVs. Understanding the patterns of technology uptake and diffusion is critical to help improve these policies and accelerate the transition to electrified modes of mobility.

This paper researched NEV policy studies with detailed bibliometric analysis based on available NEV policy studies. However, a limited number of documents are studied in this research because of the large gap in NEV policy research. Many countries have not introduced NEV products and related policies in their planning framework. Consequently, this research only studied a small number of documents related to the field which are not comprehensive.

Authors' Contributions

All authors contributed to the study conception and design. Material preparation, data collection and analysis were performed by Ruqia Shaikh and Asim Qazi. Data curation software and visualisation were performed by Asim Qazi and Xiaoli Wang. Language editing and methodology improvement were performed by Diby Francois Kassi. The first draft of the manuscript was written by Ruqia Shaikh and all authors commented on previous versions of the manuscript. All authors read and approved the final manuscript.

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Competing Interests

The authors have no relevant financial or non-financial interests to disclose.

Availability of Data and Material

There is no data used in the study except research papers extracted from the Web of Science™ Core Collection Database.

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Glossary

ACP	average citations per paper
ACY	average citations per year
AFV	alternative fuel vehicle
BEV	battery electric vehicle
EPA	Environmental Protection Agency
FAST	Firm Adoption of Sustainable Technologies
GHG	greenhouse gas
HEV	hybrid electric vehicle
ICEV	internal combustion engine vehicle
LLR	log-likelihood ratio
LSI	latent semantic indexing
MI	mutual information
NEV	new energy vehicle
PEV	plug-in electric vehicle
PHEV	plug-in hybrid electric vehicle
PRISMA	Preferred Reporting Items for Systematic Reviews and Meta-Analysis
R&D	research and development
SDG	Sustainable Development Goal
SOTC	sum of times cited
SSCI	Social Sciences Citation Index
SCIE	Science Citation Index-Expanded
TF-IDF	term frequency-inverse document frequency
TVTC	Thousands of Vehicles, Tens of Cities
WoS	Web of Science™

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