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Measuring China's new energy vehicle patents: A social network analysis approach

Huaping Sun [a, b], Yong Geng [b, a, c, d, *], Lingxiang Hu [a], Longyu Shi [e], Tong Xu [e, f]

[a] Institute of Industrial Economics, Jiangsu University, Zhenjiang 212013, China
[b] School of Environmental Science and Engineering, Shanghai Jiao Tong University, Shanghai 200 240, China
[c] China Institute of Urban Governance, Shanghai Jiao Tong University, Shanghai 200030, China
[d] Shanghai Institute of Pollution Control and Ecological Security, Shanghai 200092, PR China
[e] Key Lab of Urban Environment and Health, Institute of Urban Environment, Chinese Academy of Sciences, Xiamen 361021, China
[f] Xiamen Key Lab of Urban Metabolism, Xiamen 361021, China

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ABSTRACT

Due to increasing concerns on climate change, air pollution, and associated public health, China's new-energy-vehicle (NEV) industry has received great support and experienced rapid development. Many patents have been approved and applied in this field to support its rapid development. However, few studies investigated the evolution of these patents. Under such a background, we measure China's NEV-related patents by using a social network analysis approach. The top 38 organizations with the most NEV-related patents were chosen as the study targets. Patent numbers, technological innovation and development, and the geographical distribution of patents were examined. The cooperation network of NEV-related patents was also investigated, including its features and performance during different stages of the NEV growth. The results show that China's NEV-patents cooperation network has evolved smoothly with a growing network density, stable structure, and more cohesive subgroups. Policy recommendations were raised by considering the Chinese realities, such as the encouragement of cooperation, the creation of NEV-related patents pools, and the roles of various stakeholders.

1. Introduction

The global energy crisis and increasing transportation pollution has led to an urgent need to transfer fossil fuels-based vehicles to new energy vehicles (NEVs) [1,2]. Since the beginning of the 21st century, the NEVs industry has experienced unprecedented development. Different from traditional diesel or gasoline-based vehicles, new energy vehicles (NEVs) generally refer to hybrid electric vehicles (HEVs), especially plug-in hybrid electric vehicles (PHEVs), battery electric vehicles (BEVs), and fuel cell vehicles (FCVs). Due to their significantly less emissions, NEVs have received wide acceptance worldwide. Many countries released preferable policies to support their application, such as free vehicle plates, governmental subsidies, rapid development of charging stations, cheaper insurance fees, etc [3]. In particular, as the world's largest vehicle market, China has endeavored to support NEVs to address air pollution, climate change and public health concerns. In 2001, China launched a national major research project to solve some fundamental problems related to electric vehicles. In 2009, with the strong governmental support, the NEVs industry was listed as one of the seven strategic emerging industries. To date, China has been the largest stock of NEVs in the world, with cumulative sales of over 1.7 million units until December 2017, including passenger cars and heavy-duty commercial vehicles such as buses and sanitation trucks.

As a representative of emerging industry, NEVs adopt emerging technologies and the core of their industrial competitiveness depends on technological innovation (Ruan et al., 2017; Song et al., 2017) [4,5]. One direct output of technological innovation is patent, which reflects the latest technology progress and can serve as an effective measure on one enterprise's research and development (R&D) capacity. These patents can be classified and integrated for data analysis so that valuable information can be obtained. Such information is valuable for analyzing technological development trend, position of the investigated enterprise in the whole sector

* Corresponding author. School of Environmental Science and Engineering, Shanghai Jiao Tong University, Shanghai 200 240, China.
E-mail address: ygeng@sjtu.edu.cn (Y. Geng).

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and cooperation between different patentees. However, several academic questions still remain and need to be further addressed. For instance, what patent strategies should be adopted in order to protect the innovation achievements in this new field? What type of cooperation model should be supported to protect the benefits of patentees and promote the development of the NEVs industry? This paper attempts to answer these questions by applying a social network analysis method.

In recent years, industrial innovation has become a hot research topic. Baum et al. simulated how companies choose partners by building a network evolution model and concluded that knowledge complementarity plays an irreplaceable role and might be the real driving force for cooperative alliance [6]. Based on the dynamic analysis of two competitive innovation networks, Blundel investigated the different roles played in the innovation network by technological capability and industry dynamics [7]. Jiang et al. discussed the dynamic evolution of techno-innovation network structure from the viewpoint of network embeddedness [8]. Based on Motorola's innovative network, Chen and Vang examined the status and evolution of developing countries in the global innovation network of transnational corporations [9]. Battke found that, compared with peripheral knowledge, core knowledge is more likely to adapt to the flow of knowledge within the technology, and it is unlikely to penetrate into other technologies [10]. Geerts et al. discussed the role of the geographical dimension in explaining the ambidexterity-performance relationship and evaluated the benefits of geographic proximity between technology exploitation and exploration [11]. Binz and Truffer proposed a framework to analyze technological innovation processes in transnational contexts [12]. In addition, Hao et al. quantitatively evaluated the impact of stepped pattern of fuel consumption rate targets on automaker's lightweighting innovation strategy based on China's domestic automotive market data [13].

With regard to the development of the electric vehicle industry, several studies focused on patents and technological innovation for NEVs. For instance, taking Japan as an example, Ahman discussed the relationship of government policy and the development path of electric vehicles [14]. Brown et al. studied the role and importance of standards in an emerging market for electric vehicles [15]. Christensen argued that sharing components of power-transmission systems, such as battery power systems, hybrid power, and fuel systems, helped to implement the modular strategy [16]. Based on a comparative analysis of the entire invention patents and joint patents, Wang and Zhu examined patents development in China's NEVs industry from the perspective of industry-university-institute cooperation [17]. Bär made a comparative study of the two major NEVs countries (China and Germany) [18] and found that the development patterns of the two countries are entirely different. While China chose a government-fostering pattern, Germany adopted a market-oriented strategy. Moreover, Bär also mentioned China's strength in lithium-ion-battery technology. Based on patent data for electric vehicles, Yang et al. investigated the correlation between the relevant policies concerning electric vehicles in China and the trends in the associated technological development [19]. Yuan et al. presented a comprehensive and critical review of the policy framework for NEVs in China and discussed the development of NEVs for a sustainable future [3]. Zhang et al. analyzed how EVs will penetrate in the market, and estimated the resulting impacts on energy consumption and CO_2 emissions up to 2030 [20]. Furthermore, Ou et al. analyzed the life cycle energy consumption and GHG emissions of China's current and future multi vehicle energy technologies [21].

In general, NEVs battery technology has developed relatively slowly compared with other NEVs fields. For example, Van den Hoed gave an example of fuel-cell technology in the automotive industry [22]. Yang and Chen introduced the concept of the transnational patent and used a patent-comparative-advantage index to compare the advantages of electric vehicles in China with other NEVs power sources [23]. They concluded that the development of China's NEVs industry is imbalanced. Liu and Kokko argued that government support is needed to balance the cost advantages of traditional cars while private firms fall outside the alliances and rely on foreign collaborations [24]. Gong et al. found that lead-acid battery technology is a substantial factor in the high-volume sales of top NEV car models because of the constraints imposed by price and technological maturity [25]. In addition, Wang et al. assessed the energy reduction associated with NEVs compared with conventional vehicles (CVs) for real-world driving conditions in Beijing, China [26]. Zhao et al. evaluated the life-cycle cost and emissions of NEVs in China [27]. Chen et al. used data mining to analyze the patent-cooperation network of the top 100 patentees with the most low-carbon-vehicle patents and examined their overall characteristics [28]. Oltra and Jean analyzed the competition between the various technologies for NEVs as well as the innovative strategy of car manufacturers [29]. Frenken et al. analyzed R&D portfolios in environmentally friendly automotive propulsion including alternative fuel options [30]. Haslam et al. did a bibliometric analysis for FCV technology based on the theoretical framework of Rogers' innovation diffusion curve [31]. Finally, Sakthivel et al. introduced the current and future scenarios of Indian transportation, petroleum oil, and bio-fuel sectors including global progress on using ethanol as an alternative transportation fuel in spark-ignition vehicles [32].

These studies mainly focus on the direct analysis of patent data, such as the distribution of patent numbers and patent applicants and other preliminary descriptive statistics. Social networks and other methods were used to study the evolution of the NEV patent-cooperation network. However, few scholars measured the potential of the patent pool based on China's NEV patent data. By establishing patent cooperation network and evolution analysis, this study aims to uncover the potential of the NEVs industry's technological innovation and patent-pool construction in China.

The remainder of this paper is structured as follows: Section 2 depicts research methods and data, Section 3 presents the research results, Section 4 presents policy recommendations and Section 5 draws research conclusions.

2. Methods and data

2.1. Data sources

The patent data used in this paper are derived from the patent retrieval and analysis system built by the State Intellectual Property Office of China (SIPO). Scholars usually use the international patent classification number (IPC) or keywords search method, or combine the two methods when searching for new energy vehicle technology patents. One drawback of this IPC retrieval is that the determination of classification number is controversial, which may cause omissions. The keywords search method can be combined to retrieve the technology of different patent classifications by defining key words. It can overcome some shortcomings of the IPC retrieval method and ensure the accuracy of the patent information. However, the IPC classifications for some emerging industries have some problems. For example, a number of IPC classifications may exist in one patent. In order to solve such a problem, we adopt keywords search method to avoid omissions [29–31].

The keywords used in this study include hybrid electric vehicle, electric vehicle, plug-in electric vehicle, and fuel vehicle. All of them were defined by Ministry of Industry and Information Technology of the People's Republic of China in 2009. The investigation period for this study is from January 1, 2016 to December 31, 2016. China's 38 top NEVs enterprises with most relevant patents were chosen by using the keywords search method. These enterprises have 5699 patents, including 647 cited patents.

2.2. Social network analysis

A social network is a social structure made up of a set of social actors (such as individuals or organizations), sets of dyadic ties, and other social interactions between actors. Social-network analysis serves to analyze the structure of entire social entities. Several theories can explain the patterns observed in these structures. This method can help identify local and global patterns, locate influential entities, and examine network dynamics [7]. It is an interdisciplinary academic method used in social psychology, sociology, statistics, and graph theory. To date, it has been widely used in social sciences. With regard to innovation research, social-network analysis is a major method because of its interdisciplinary nature.

2.2.1. Network structure analysis

2.2.1.1. Distribution of network node degree. Many nodes are connected by edges to create a complex network. The degree of a node describes the edge connection: the larger the degree, the greater the number of connections. The analysis of node degree in a network can help to understand the overall features of the network structure.

2.2.1.2. Analysis of network coherency. Network coherency is mainly measured by network density, the average distance between nodes, and cohesion. A higher network density indicates a closer connection between nodes and a greater impact of the whole network on the nodes. The average network distance refers to the mean distance between nodes within the network and can reflect the relationship between nodes.

2.2.1.3. Network density. Network density refers to the ratio of the actual number of connected nodes to the potential maximum number of connected nodes in a network. A higher density indicates a closer relationship between industries and higher profits. In contrast, a lower density indicates an exiguous relationship and a lower degree of linkage within the network. The formula for calculating network density is

$$D = \frac{T}{n(n-1)} \tag{1}$$

where T is the actual number of connections, n is the number of nodes in the network, and $n(n-1)$ is the potential maximum connection of the industrial network.

2.2.2. Centrality

Centrality reflects the importance of one node within the entire network. Several centralities are defined below.

2.2.2.1. Degree centrality. Degree centrality is the number of nodes that are directly connected to other nodes. The greater the degree centrality, the more nodes are connected to a certain node. Such a node is generally in the center of the investigated network and greatly influences other nodes. If a network is directed, meaning that one edge points in one direction from one node to another node, then this node has two different degrees: the in-degree, which is the number of incoming edges, and the out-degree, which is the number of outgoing edges. Equation (2) shows how to calculate degree centrality,

$$C_D(\mathrm{n}_i) = d(n_i) = \sum_j x_{ij} = \sum_j x_{ji}\mathrm{a} \tag{2}$$

where $d(n_i)$ represents the degree centrality, and $\sum x_{ij}$ represents the number of direct contacts between nodes i and j ($i \neq j$).

2.2.2.2. Betweenness centrality. Betweenness centrality is a measure of centrality in a graph based on shortest paths. It refers to the degree of control of one node on a resource. If the connection between other nodes needs to pass through a node, the betweenness centrality of this node is high. Equation (3) shows how to calculate betweenness centrality,

$$C_{ABi} = \sum_j^n \sum_k^n b_{jk}(i), j \neq k \neq i, \quad j < k, \tag{3}$$

where $b_{jk}(i)$ represents the ability of node i to control the connection between nodes j and k.

2.2.2.3. Closeness centrality. Closeness centrality of one node measures its centrality within one network and can be calculated as the sum of the lengths of the shortest paths between this node and all other nodes in the network. The more central a node, the closer it is to all other nodes. Such nodes are generally located at the center of a network. On the contrary, a node with a longer distance tends to be weaker in terms of resource control and influence and is usually on the edge of the network. Closeness centrality is calculated by using Equation (4):

$$C_{APi}^{-1} = \sum_{j=1}^n d_{ij}, \tag{4}$$

where d_{ij} is the distance between nodes i and j.

3. Results and discussions

3.1. Current situation analysis

3.1.1. Number of patent applications

A keywords search shows that, except for design patents, the total number of applications for NEVs-related patents from 2001 to 2016 is 25 607, which includes 15 047 invention patents and 10 560 patents for utility models. Fig. 1 shows a histogram of patent applications for China's NEVs industry. It is clear that only a few patents were approved before 2001. Between 2001 and 2008, the number of approved patents grew steadily, but the number of applications remained less. In 2009, patent applications exceeded 500, indicating that research and development (R&D) activities on NEVs was increasing. The annual number of patents has not decreased since 2013, reaching 7376 in 2016.

3.1.2. Distribution of patentees

The 38 selected companies hold a total of 5699 patents. Table 1 shows the top 20 patentees with the most patent applications, including NEV enterprises and related research and development organizations (universities and research institutes). Among all the companies investigated, Chery Automobile Co., Ltd. holds the largest number of patents (759). BYD AUTO, Beiqi, and Foton are ranked second, third, and fourth, respectively. Among the universities and research institutes, Tsinghua University in Beijing holds 284 patents, ranking first, followed by Shandong University of Technology, Jilin University, Jiangsu University, and Tongji University. All of these universities have more than 100 patent applications.

3.1.3. Distribution of patent technologies in different areas

Fig. 2, which was prepared by the IPC, shows the distribution of NEV-related patent technologies in different fields and their evolution. The five technological fields are B60L, B60K, H02J, H01M, and H02K (see Table 2), with B60K and B60L being the top two (they belong to the B60 category of electronic control). This indicates that the rapid development of NEVs induced a rapid development of electronic control technologies. Also, domestic enterprises and research organizations have relatively mature technologies in the fields of car chassis and bodies. Of all the technologies, H02K is the least represented, whereas H02J and H01M experienced rapid development (especially H02J), which reflects that power-distribution and power-supply systems have become top research priorities. This indicates that more research attention is being devoted to improving NEV-related infrastructure. This is rational because NEVs cannot be widely accepted by consumers without appropriate and convenient infrastructure.

Fig. 2 also shows that the total number of patents on various technologies has decreased significantly since 2012. On the one hand, it indicates that the relevant technologies have become saturated; on the other hand, relevant policies also had significant impacts, leading to a substantial patents increase in the major technological areas. Historically, national policies supporting NEVs first focused on the comprehensive development during 2000–2010. To fill the technological gaps, almost every aspect of NEVs was encouraged in the initial stage. Later, after more patents were approved, policies began to focus on some key technologies, especially batteries, electric motors, and electronic control, while other aspects received less attention. Meanwhile, progress in global research on such fields began slowly, which further decreased the overall patents after 2012.

3.1.4. Geographical distribution of patentees

The 25 607 retrieved patents were classified according to geographical locations, as shown in Fig. 3. The top eight provinces include Beijing, Shanghai, Jiangsu, Anhui, Guangdong, Zhejiang, and Hubei. These eight provinces accounted for 72.97% of all the NEV-related patents in China. Beijing has the most patents with a share of 12.79%, while Shanghai has the second most with a share of 12.11%. Hubei has the fewest patents among the top eight provinces, with a share of 5.12%. This indicates that China's NEV research activities are relatively balanced. It also indicates that the competition is quite fierce in China's NEV market.

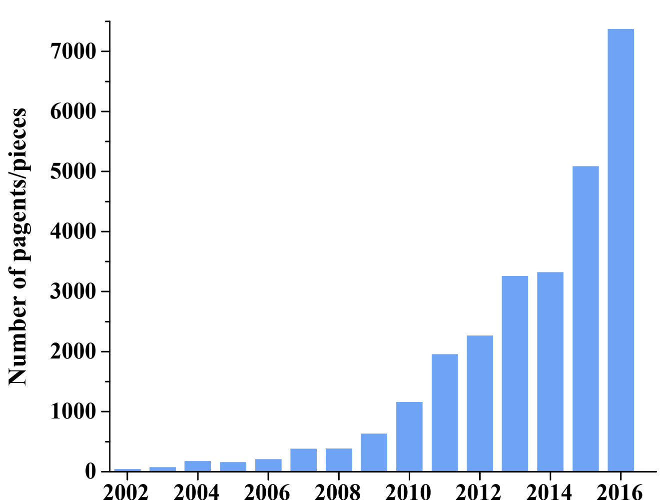

Fig. 1. Histogram of patent application in China's new energy vehicle industry.

3.2. Analysis of network characteristics

3.2.1. Macroscopic features of patent-citation network

Patent citation network is an important carrier of technology cooperation and knowledge spillover. Such a network can show the position of one enterprise in the network, the mode of knowledge transfer and its efficiency. At the same time, it can identify the core patents and promote future technological development. A 38 × 38 patent-citation matrix was established by using the patents from the top 38 Chinese patentees. Then this matric was imported to the software UCINET, which is widely used for network analysis. As a result, a patent cooperation network diagram (Fig. 4) is generated for further understanding the cooperation behaviors among different patentees.

As shown in Fig. 4, all the nodes represent the top 38 leading NEV organizations, including enterprises represented by squares, and research and development institutions represented by circles. The thickness of one connection edge between two different nodes represents the total citations between the two nodes. The structure features of this network can be reflected by the network concentration, density, efficiency, cohesive subgroups, etc. Table 3 lists the key results.

Theoretically, the maximum number of network lines would be 703 (38 × 37/2). In this case, the total number of network lines is 303, and the total number of network connections is 934. There are no isolated points in the entire network. According to the UCINET analysis, the network density is 0.6662, indicating frequent cooperation between patentees. The degree centrality of this network is 16.45%, meaning that most patentees only need several intermediaries to create bridges to connect to others. In terms of efficiency, the average distance of this patent citation network is 1.951 and the cohesion distance is 0.476, indicating that these network nodes are closely linked and the efficiency for patent transfer is high. There are 22 cohesive subgroups. BYD AUTO involved in 11 of these subgroups and thus has an indispensable role. In general, this patent-citation network evolves gradually, indicating that NEV enterprises and relevant research and development organizations are establishing close partnerships.

3.2.2. Features of patent-citation network nodes

The degree centrality of 16.45% and the betweenness centrality of 16.29% indicate that nodes in this patent-citation network have different positional advantages. While some nodes locate at the center of this network, most nodes locate at the edge of this network. Table 4 lists the descriptive statistics of the three centralities, and Table 5 lists the three centralities for the top 15 patentees. The mean degree centrality and betweenness centrality are 24.58 and 26.40, respectively, which means that, among the 38 patentees in the network, each patentee has cooperative partnerships with 24.58 patentees and on average serves as an intermediary for 26.40 times.

However, these centrality indicators are distributed unevenly among the 38 patentees. Some nodes are larger, indicating that core areas exist within the patent cooperation network (Table 5). For instance, Chery Automobile and Chongqing Changan have larger centralities, which means that they cite the other patents more frequently. The centralization of standardized in-degree and out-degree is 23.7% and 15.1%, respectively. A greater centralization means that citations are concentrated in the central part of this network. Chery Automobile, Chongqing Changan, and BYD AUTO have significantly higher betweenness centralities than other patentees. These three patentees are thus the key sources of related knowledge and technologies. They dominate most of the patent-

Table 1
Patents owned by different vehicle companies.

Ranking	Patentee	Number of patents	Ranking	Patentee	Number of patents
1	CHERY	759	20	HEEC	109
2	BYD	414	21	QYEV	105
3	CHANGAN	395	22	YUTONG	102
4	BEIQI FOTON	327	23	SUDA	96
5	THU	284	24	LIFAN	95
6	GEELY	226	25	CRRC	90
7	JAC	224	26	DAYOU	84
8	SAIC	217	27	GWM	79
9	DFAC	177	28	GAG	74
10	BAIC	163	29	ANKAI	73
11	SDUT	157	30	ZOTYE	66
12	JLU	152	31	WEICHAI	62
13	UJS	146	32	BZHAC	60
14	TJU	135	33	SANTROLL	57
15	SEC	129	34	SFCVPC	47
16	CQU	127	35	Southeast (Fujian)	43
17	SZSEVC	126	36	ZJGJN	38
18	FAW	117	37	ZHONGTONG	24
19	BIKE	114	38	JMC	8

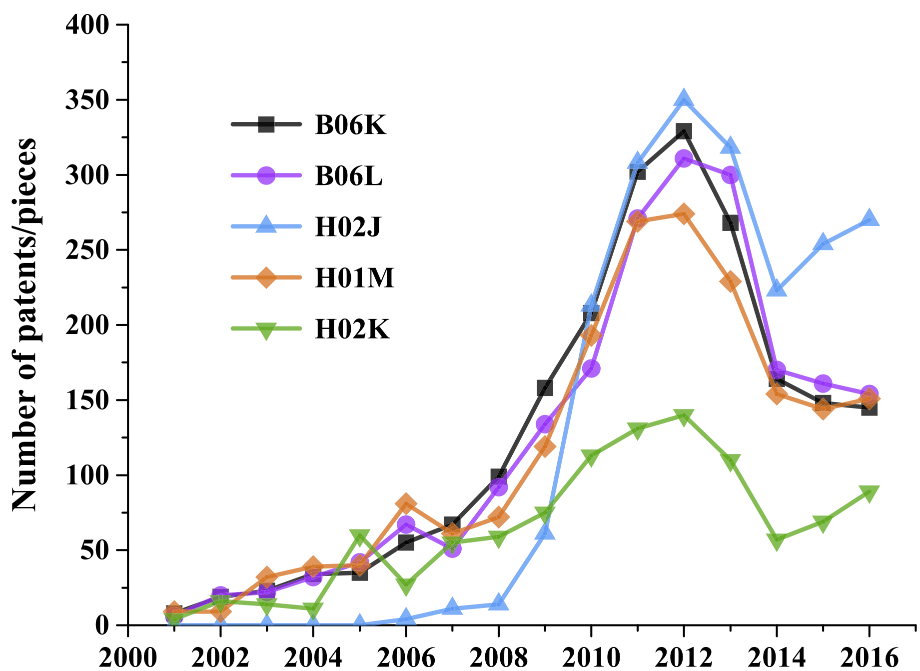

Fig. 2. Distribution of patent technology of new energy vehicles in different areas in China.

Table 2
Interpretation of the five technological fields.

Abbreviation	Interpretation
B60L	power unit or electronic equipment of electric vehicles; used for magnetic suspension or suspension, electric brake system for common vehicles
B60K	the arrangement or installation of power unit or transmission device of a vehicle; the arrangement or installation of two or more different prime motor; auxiliary drive; vehicle instrumentation or dashboard; combined control for driving device; the arrangement of power unit and cooling device, intake and exhaust system, or fuel supply system
H02J	circuit device for power supply or power distribution; electric storage system
H01M	device that converts chemical energy directly into electrical energy, like battery pack
H02K	dynamo-electric machines (measuring instruments G01; dynamo-electric relays H01H53/00; conversion of dc or ac input power into surge output power H03K3/53; loudspeakers, microphones, gramophone pick-ups or like acoustic electromechanical transducers H04R)

citation relationships within the network. Being close to the centrality means that the network has a good overall connection performance and the network structure is stable.

From the perspective of the three centralities, Chery Automobile, Chongqing Changan Automobile, and BYD AUTO are core members. Fifteen organizations are classified as middle-level members, including Tsinghua University, Chongqing University, Beiqi Foton, SAIC Motor Corp, Geely Group, CSR Times Electric Co.,

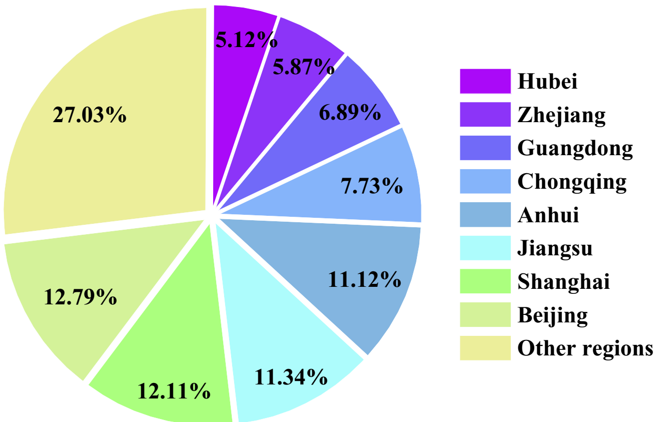

Fig. 3. The geographical distribution of the patentees in China.

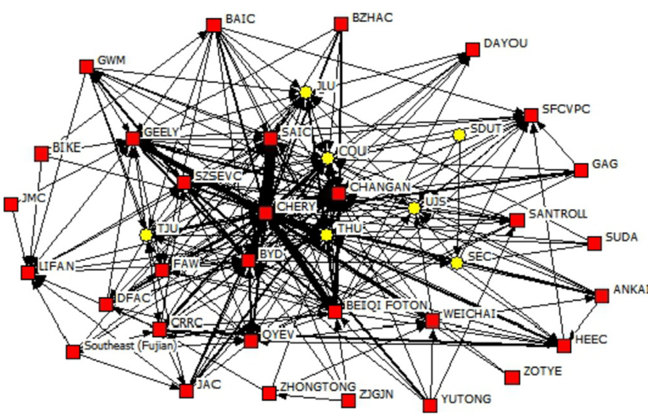

Fig. 4. Citation network from 2001 to 2016.

Ltd, Weichai Power, Shanghai Zhongche, Shenjiang Electric Vhicle Co., LTD, Tongji University, Yineng Power Group, Dongfeng Automobile, Jilin University, China FAW Group, Tianjin Qingyuan Electric Vehicle Co., Ltd and Shanghai Fuel Cell. The other twenty patentees are classified as marginal members, including Beijing Automotive Group Co., Ltd, Anhui Jianghuai Automobile Co., Ltd, Great Wall Automobile, Guangzhou Automobile Group Co., Ltd, Jiangsu University, etc. These organizations obtained fewer patent references or citations due to their higher out-degrees and lower betweenness centrality, leading to less influence on the citation relationships. In this network, there are no "potential" members, which are members without any references or citations and with a zero betweenness centrality.

3.3. Evolution analysis of patent-cooperation network

s NEV patent cooperation can be divided into three stages: initial development period (2001–2008); incubation stage (2009–2012) featured by rapid growth due to the national support; and strategic development stage (2013–2016) featured by stable development and national planning. Figs. 5–7 show these three different stages of the patent cooperation network, in which one square represents one single NEV manufacturing enterprise and one circle represents one single research and development organization. The direction of an arrow (such as A → B) means that B's patent is referenced or cited by A. A thicker line means more citations or references. Table 6 lists the key parameters of the patent citation network in the three different stages.

3.3.1. Initial development period

At this stage, both the number of cooperation between the patentees (21) and the number of partners (14) are small. Few NEV patents were approved. The top patentee received 41 patents, while some patentees did not even have one patent. Network density was only 0.0149. The whole network structure is fragmented and there is only one cohesive subgroup. Among all the patentees, Tsinghua University and Tongji University are the key players with respect to the circulation of their NEV-related knowledge and technologies to NEV manufacture companies. Their key industrial partners include BYD AUTO and Chery Automobile.

3.3.2. Incubation stage

The period of 2009–2012 is a key stage for incubating NEV technologies. Many patents were approved and applied through technological exchanges and close cooperation between different patentees. The network density increased to 0.3029 and the number of cohesive subgroups reached seven, indicating more connections between different nodes. At this stage, patents from Chongqing University and Jilin University increased significantly and were cited more frequently. More NEV enterprises joined the network and the industrial NEV chain gradually developed. More NEV companies invested in research and development activities, further promoting the technological progress of NEVs.

3.3.3. Strategic development stage

At this stage, the patent-cooperation network continued to expand. More cooperation activities occurred among different

Table 3
Feature parameters of patent citation network.

Number of network edges	Number of network connections	Network centrality	Network density	The average of the standard degrees	The average of the standard deviation	Efficiency measurement		The number of condensed subgroups
						Average distance	Cohesion based on distance	
303	934	16.45%	0.6662	7.079	17.18	1.951	0.476	22

Table 4
Descriptive statistics of the three centralities.

	Average	Standard deviation	Sum	Variance	Minimum	Maximum	Centrality
Degree centrality	24.58	26.10	934	618.09	2	108	16.45%
Betweenness centrality	26.40	44.518	1003	1981.89	0	237.61	16.29%
Closeness centrality	386	565.86	14693	320192.50	41	1406	/

Table 5
Calculation results of three network centralities (only the top 15 organizations are listed below).

Degree centrality			Betweenness centrality			Closeness centrality		
node	OutDegree	InDegree	node	Betweenness	nBetweenness	node	inFarness	outFarness
CHERY	108	300	CHERY	237.61	17.84	CHERY	41	382
CHANGAN	92	118	BYD	98.39	7.37	CHANGAN	48	385
BEIQI FOTON	83	16	CHANGAN	85.64	6.43	THU	50	392
SAIC	70	20	CQU	68.22	5.12	BYD	53	384
GEELY	65	23	QYEV	67.16	5.04	CQU	53	393
BYD	60	86	GEELY	60.94	4.58	JLU	59	396
THU	39	75	CRRC	60.90	4.57	GEELY	59	389
CRRC	29	18	THU	56.58	4.25	SFCVPC	61	408
WEICHAI	27	3	UJS	51.65	3.88	FAW	61	396
BAIC	27	1	WEICHAI	47.07	3.53	QYEV	61	398
JAC	24	2	BEIQI FOTON	36.92	2.77	CRRC	64	387
GWM	24	4	ZJGJN	36.00	2.70	SZSEVC	64	393
HEEC	22	9	SAIC	21.56	1.62	SAIC	64	394
SZSEVC	20	21	JLU	11.39	0.86	TJU	65	391
TJU	20	15	LIFAN	9.01	0.68	BEIQI FOTON	66	383
BZHAC	19	0	SZSEVC	8.98	0.67	HEEC	68	397
DFAC	18	11	SEC	7.01	0.53	SANTROLL	68	398
CQU	16	62	HEEC	7.01	0.53	DFAC	69	393
JLU	15	30	TJU	6.82	0.51	DAYOU	72	403
Southeast (Fujian)	14	0	FAW	5.81	0.44	UJS	75	397
GAG	14	1	BAIC	3.82	0.29	ZJGJN	77	398
UJS	14	8	SANTROLL	3.80	0.29	LIFAN	78	401
YUTONG	13	0	ZHONGTONG	2.86	0.22	GWM	78	393
SANTROLL	13	6	GWM	2.32	0.17	SEC	84	401
FAW	12	37	DFAC	1.84	0.14	WEICHAI	92	391
QYEV	12	26	JAC	1.24	0.09	JAC	99	394
ANKAI	12	1	GAG	1.19	0.09	GAG	110	398
LIFAN	11	9	SFCVPC	0.50	0.04	ZHONGTONG	111	401
SUDA	7	0	DAYOU	0.45	0.03	ANKAI	126	397
ZJGJN	6	1	ANKAI	0.34	0.026	BAIC	1369	357
SEC	5	5	ZOTYE	0	0	ZOTYE	1406	372
DAYOU	5	5	SDUT	0	0	SDUT	1406	374
BIKE	4	0	JMC	0	0	JMC	1406	378
ZHONGTONG	4	1	BIKE	0	0	BIKE	1406	331
SDUT	4	0	BZHAC	0	0	BZHAC	1406	364
ZOTYE	2	0	SUDA	0	0	SUDA	1406	366
JMC	2	0	YUTONG	0	0	YUTONG	1406	360
SFCVPC	2	20	Southeast (Fujian)	0	0	Southeast (Fujian)	1406	358

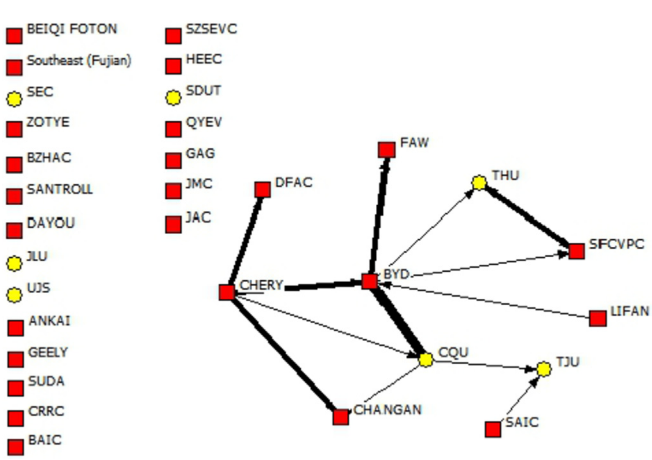

Fig. 5. Patent cooperation network for the period of 2001–2008.

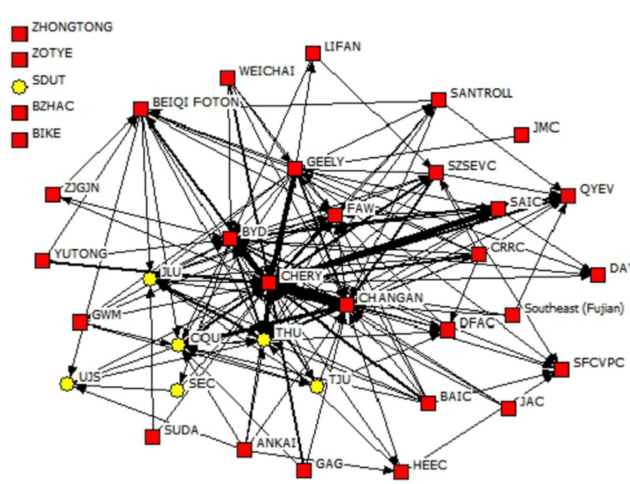

Fig. 6. Patent cooperation network for the period of 2009–2012.

patentees. Network density reached 0.3516, indicating that the entire network became more stable. The network degree centrality increased from 8.51% (2001–2008) to 11.57% (2009–2012) and finally to 12.82% in the strategic development stage, and the number of cohesive subgroups reached 12. In particular, NEV-part producers received more patents, with an annual growth rate of 20%. This indicates that R&D activities began to move to those upstream companies and the optimization of the entire life cycle of NEV occurred.

4. Policy suggestions

China's current support policy for NEVs is mainly to provide

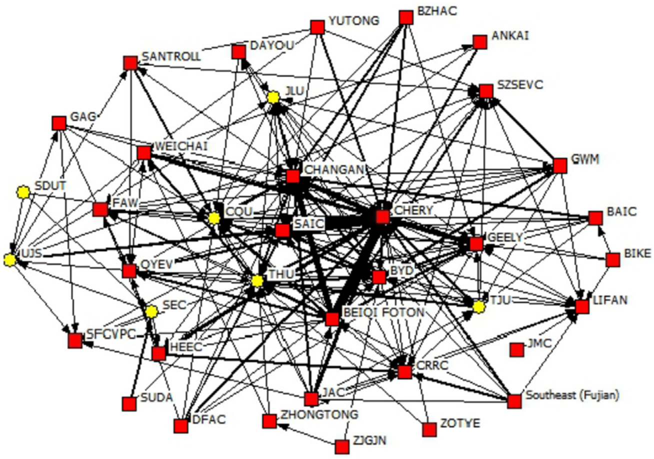

Fig. 7. Patent cooperation network for the period of 2013–2016.

financial subsidies. However, more measures should be taken to further encourage technological innovation.

First, both horizontal and vertical patent cooperation should be encouraged. Horizontal cooperation refers to cooperation between NEV enterprises, while vertical cooperation refers to cooperation between research institutions and NEV enterprises. Regarding horizontal cooperation, because NEV enterprises face similar challenges, it would be rational for them to exchange the most recent technological information so that they can avoid investing in similar researchfields. In this regard, a trading platform should be created so that they can fairly make their patents transactions. Regarding vertical cooperation, because many research institutions are not familiar with the real needs of NEV enterprises, it would be crucial to promote their communication so that research institutions can identify the key research topics. Both national government and local governments can help through the "Government-University-Industry Cooperation" model. Such a model can ensure that the cooperation between research institutions and NEV enterprises be more successful since all the involved parties will conduct relevant activities under the framework of intellectual property protection laws.

Second, it is critical to create patent pools so that relevant industrial standards can be established. A patent pool is a consortium of at least two companies agreeing to cross-license patents relating to a particular technology. The creation of a patent pool can save patentees and licensees time and money. In the case of blocking patents, it may also be the only reasonable method to make the invention available to the public [32]. Although China's NEV technologies have been widely developed, the proven patents are from different areas and many patentees do not share their knowledge and expertise with other stakeholders. Such a fragmented distribution of patents cannot facilitate the further rapid development of the NEV industry. Consequently, the Chinese government should help establish NEV-related patent pools. Such a measure would facilitate the release of relevant industrial standards so that NEV enterprises can follow such standards and improve their products quality. The creation of patent pools would also maximize knowledge spillover and technology diffusion, reduce costs and risks of NEV enterprises, and encourage more technological innovations. However, legal issues remain and need to be further strengthened, such as the avoidance of technological monopoly, the implementation of fair, reasonable, and non-discriminatory principles, and appropriate standards for patent-assignment fees, etc.

Last but not least, it is rational for all the stakeholders to clarify their roles. Different stakeholders have different concerns and interests. Conflicts may not be entirely avoided. Any conflicts may impede the successful cooperation among different stakeholders. Thus, better communication, the exchange of information and extensive interactions between different stakeholders and levels are essential requirements. In this regard, it is appropriate to set up a roundtable so that stakeholders can share their views and concerns publicly. However, such an approach would be unique in China, since public participation on public affairs is still limited and weak. Therefore, further capacity building programs may be necessary so that all the stakeholders can improve their awareness and skills through activities, such as TV promotions, newsletters and regional symposia and workshops. These activities will build their mutual understanding since they can provide forums at which expertise and experiences from different stakeholders could be objectively reviewed and lessons drawn.

5. Conclusions

NEVs can help address climate change and mitigate air pollution and thus deserve to be fully supported by public policies. The development of NEVs is based on the rapid development of related technologies. The total number of patents related to NEVs is one indicator to measure the progress of such technologies. Under such a circumstance, this study investigates China's NEV-related patents to uncover the evolution trends of these technologies. A social network analysis method is applied to investigate NEV patents. The results show that the NEV industry in China grew rapidly from 2001 to 2016, as reflected by the increasing number of patents and more cooperation activities between patentees. China's top NEV enterprises contributed significantly to this patent base and became core patentees. The network density also increased during this period as more members joined the network, indicating a stable evolution of the patent network. When the network became saturated, research priorities began to focus on batteries, electronic control, and electric motors. The total number of approved patents also began to decrease. Patentees were distributed dispersedly with low concentration ratio. Based upon these findings, policies to promote more technological innovations are raised by considering the Chinese realities so that the NEV industry can move toward sustainable development.

Table 6
Basic parameters of patent citation network at different stages of China's new energy vehicle industry.

Stage	Node	Number of edges	The number of cooperation	Network density	Network centrality	Network tightness	The number of condensed subgroups
2001–2008 Patent citation network	38	14	21	0.01	8.51%	0.01	1
2009–2012 Patent citation network	38	171	425	0.30	11.57%	0.32	7
2013–2016 Patent citation network	38	217	494	0.35	12.82%	0.38	12

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