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How IoT-Enabled New Energy Vehicles Enhance Sustainable Intelligent Transportation Systems in Smart Cities Under Unique Institutional Settings? Case Studies of China

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Abstract: The purpose of this paper is to study how government policies influence the advancement of IoT-enabled new energy vehicles (NEVs) in the context of sustainable intelligent transportation systems (ITS) in smart cities. As a crucial component of a smart city, the intelligent transportation system is the core of the development of urban transportation, whereas new energy vehicles comprise a critical element in ITS. Additionally, IoT is transforming vehicles with intelligence. Consequently, this paper starts with a bibliometric analysis to uncover hot spots to better comprehend China's NEV industry. Further, this paper also examines the applications of IoT in NEVs and the current scenario of new energy vehicles in China by investigating multiple policies proposed by the government. Finally, the case of Guangdong province will be utilized as an illustration to promote IoT integration in the development of NEVs.

Keywords: internet of things; new energy vehicle; intelligent transportation system; smart city; case study

1. Introduction

The term "smart city" refers to a city that employs information and communications technology to make city services and monitoring more interactive and effective (Jin et al., 2014). Intelligent transportation systems have evolved as a key component of smart cities, integrating network-based information (such as vehicular networks, and wireless sensor networks) and electronic technologies (such as sensors, and cameras) with transportation technologies. The Internet of Things is a recent communication paradigm that envisions a near future, in which the objects of everyday life will be equipped with microcontrollers, transceivers for digital communication, and suitable protocol stacks that will enable them to communicate with one another and with the users, becoming an integral part of the Internet (Zanella et al., 2014; Yu, Song, Sampat, et al., 2023). The smartness of a transportation system is driven and enabled technologically by the emergent Internet of Things. With increasing attention to environmental protection and advances in technology, new energy vehicles are soaring nowadays and comprise a critical element in ITS (Menouar et al., 2017). In the meantime, sufficient charging infrastructure (CI) is the bedrock in that it not only underpins the upgrade of the NEV industry but also serves as a platform for emerging industries linked to sustainable ITS like energy storage, wireless charging, and smart grid. Under this circumstance, the applications of IoT in new energy vehicles will be more variable and wider, together breathing new life into sustainable ITS. China has constructed rather relatively sophisticated charging infrastructures. Consequently, this paper will first conduct a bibliometrics analysis on new energy vehicles, the internet of things, and intelligent transportation systems. Then, this paper will examine the applications of IoT in new energy vehicles. Further, this paper will investigate the current scenario of new energy vehicles in China and then utilize Guangdong province, as an illustration, to demonstrate the function of government policies in the development of NEVs in the context of intelligent transportation systems. Moreover, this paper will provide suggestions for the government to deal with the problems that occur in the field of NEVs which are instructive for the construction of intelligent transportation systems in other provinces in China.

2. Methodology

The research method applied for the paper is qualitative because the research required the need to understand how and why IoT-enabled new energy vehicles enhance sustainable intelligent transportation systems in smart cities. Qualitative research is characterized as a method for investigating and grasping the significance that individuals or groups assign to social or human issues (Creswell, 2009; Klein & Myers, 1999). Given that the data in the paper examined the development of new energy vehicles in China was qualified rather than quantified, the qualitative technique was determined to be the preferred method for the study.

The case study was adopted as the research approach to present a full overview of China's new energy vehicle evolution and how the government aids it through policies. The case study is a type of empirical investigation that concentrates the subject of study to one or a limited number of units while investigating a contemporary phenomenon in depth and a practical setting (Creswell & Poth, 2018; Eisenhardt & Eisenhardt, 1989; Swanborn, 2010; Yin, 2015). The advancement of new energy vehicles is a contemporaneous event with real-life consequences, and everyone possesses little or no control over the event, which made the case study the best candidate for the conduct of the research. Yin (2014) detailed the characteristics of case studies, including an in-depth comprehension of the case, a description of the case, and the researcher's conclusion is shaped by the overall meaning extracted from the case. This paper will follow the same pattern as above.

3. Literature Review

This section adopts the bibliometrics analysis method and conducts advanced retrieval with" new energy vehicles", "internet of things" and "intelligent transportation system" as the main epigrapher in Web of Science. Furthermore, the internet of things is analyzed using *CiteSpace* to discover what's hot now and possible future trends. Concerning the parameter setting of *CiteSpace*, the period of the literature is approximately ten years from 2013 to 2022 with time slicing for one year per slice, and the number of qualified records on these three topics of IoT is 20777. This section focuses on keyword co-occurrence analysis and co-country network analysis. Keyword co-occurrence analysis is an effective way to elucidate the structure of scientific knowledge, explore research hotspots, and discover research trends (Chen et al., 2002). Also, it represents the core contents of the research papers (Yu, Chen, et al., 2024; Yu, Xu, et al., 2024a, 2024b). Overall, hot research areas and frontier research topics can be determined by investigating the keyword co-occurrence-based knowledge maps and burst keywords. Co-country network is used to analyze the joint research in a certain research field to reflect the level of importance and contribution of each country to the topic.

3.1. New Energy Vehicle

New energy vehicles (NEVs), and especially electric cars, are rapidly changing the outlook of the car industry in China, the largest vehicle market in the world (Hu et al., 2021; Yu, Chang, et al., 2023). Electric mobility is emerging all around the world with the goals of minimizing environmental impacts, reducing dependency on petroleum, and diversification of energy sources for transportation (Onat & Kucukvar, 2022). The overall Chinese NEV development process from 2003 to 2015 experienced three representative stages—an industrial exploration stage, a fostering stage, and a development stage (Du & Ouyang, 2017; Yu, Xu, Cheng, et al., 2023). The production of NEVs in China did not commence until 2005. The National Development and Reform Commission (NDRC) released "Announcement for Vehicle Manufacturers and Products" in April 2005 (Yuan et al., 2015). Generally, the development of energy-efficient and new energy vehicles in China is supported by three main factors, namely the severe situation of energy and environment, the rapid development of technologies, and supportive policies by the government (Liu et al., 2018). Several scholars have also emphasized that the main obstacles to the widespread adoption of NEVs are an absence of sufficient charging infrastructure, the distribution of charging stations, and the schedule of charging at charging stations (Lebrouhi et al., 2021). An additional critical issue will be to determine which of the numerous technologies and load specifications should prevail and dominate the load of future NEVs (Das et al., 2020). NEV charging infrastructure is classified into conductive and inductive charging (Khalid et al., 2019). Conductive charging involves direct metal-to-metal contact between the utility grid and the NEV to transfer the power to the NEV. Inductive or wireless charging infrastructures utilize the principle of mutual induction for transferring power between the utility grid and the EV which requires no physical contact between the utility grid and NEV. Hence, to address the increasing needs, the construction of supporting infrastructures and facilities must be expedited. China still has a long way ahead of it before new energy vehicles are industrialized and extensively deployed (Yu, Hu, Prakash, et al., 2023).

3.2. Intelligent Transportation System

In numerous cities, authorities and transport operators have been making investments in information and communication technology (ICT) to promote digitalization and convert these areas into smart cities (Silva et al., 2018). Intelligent Transportation Systems (ITS), one example of ICT, aims at facilitating urban mobility economically and ecologically by connecting vehicles with the network infrastructure. In general, five types of services are expected to be provided by ITS, namely: (i) intelligent transportation, such as routing planning and navigation, avoiding traffic jams, and (ii) Safe driving assistance such as traffic monitoring and management and active safety. (iii) Driver or vehicle-related services, such as fines for breaking traffic rules, and automatic maintenance of vehicles. (iv) Entertainment and advertisement, such as streaming video, etc. (v) Providing environmental data, including traffic data obtained through crowdsourcing. (Li et al., 2020; Guevara & Auat Cheein, 2020). All of these envisioned applications require each vehicle to be connected via a universal and ubiquitous vehicular network enabled by wireless communications, such that they can act cooperatively (Cheng et al., 2015). ITS generates data with higher granularity, which overcomes the past limitations due to highly aggregated data and poses new challenges regarding data integration, analysis, and visualization (Sobral et al., 2019). ITS systems rely on automated sensors and adjust their functions to changes in the environment. While the use of sensors and electronics brings benefits it also increases systems' complexity and vulnerability. Thus, infrastructure systems are becoming more vulnerable to unknown hazards or risks, whose likelihoods and mechanisms may be poorly understood (Ganin et al., 2019).

3.3. Internet of Things

The term "Internet of Things" (IoT) was introduced by Kevin Ashton in 1999 (Alaba et al., 2017; Yu, Neu, et al., 2024). Smartphones, embedded systems, wireless sensors, and almost every electronic device are connected to a local network or the internet, leading to the era of the IoT. With the advent of the IoT, people, things, sensors, and services are now constantly connected around the globe. Three parts form the base of IoT design: (1) perception layer: sensor knots, allure rooted concepts, and connect circuits are all covered. (2) Network layer: It involves of data conversion, study, and management possession. (3) Application layer: It involves effective imagination finishes that are agreeable accompanying differing podiums for various uses and present the dossier completely consumer in a comprehensible form (Ammar et al., 2018; Yu, Zhao, & Hanes, 2023; Yu, Zhao, & Sampat, 2023). The primary goal of IoT is to create a network infrastructure with interoperable communication protocols and software to enable the connection and incorporation of physical and virtual sensors, PCs, smart devices, cars, and objects like refrigerators, dishwashers, microwave ovens, food, and medications, anytime and on any network (Hassan et al., 2020; Yu, Lang, Galang, et al., 2023).

After performing the keyword co-occurrence analysis on *CiteSpace*, the results of cluster analysis are presented in Figure 1. The top 20 keywords ranked by the number of counts in IoT-related research are listed in Table 1. Centrality reflects the importance of nodes in the network structure, the greater the centrality represents the more prominent role of nodes in mediating and transmitting information flow, nodes with centrality above

0.1 are often considered as high-centric nodes and have a critical position in the network. Silhouette score S and Modularity Q are the evaluation metrics of the modularity of the co-linear network, and the larger the Q and S of the network, the better the clustering of the network. When $Q > 0.3$ means that the clustering structure is significant; when $S > 0.5$ is generally considered reasonable, $S > 0.7$ means that the clustering is convincing.

Table 1. Top 20 keywords ranked by number of counts related to IoT.

Rank	Count	Centrality	Year	Keywords
1	10022	0.12	2013	internet of thing
2	1874	0.10	2013	system
3	1439	0.07	2013	network
4	1388	0.11	2013	wireless sensor network
5	1019	0.03	2013	security
6	1005	0.11	2013	challenge
7	989	0.07	2013	cloud computing
8	963	0.04	2013	iot
9	955	0.07	2013	management
10	950	0.06	2013	design
11	928	0.04	2013	algorithm
12	880	0.02	2013	model
13	833	0.04	2013	scheme
14	802	0.01	2017	edge computing
15	783	0.01	2016	machine learning
16	760	0.08	2013	framework
17	714	0.04	2013	architecture
18	703	0.06	2014	big data
19	700	0.09	2013	optimization
20	672	0.02	2013	protocol

Source: Web of Science

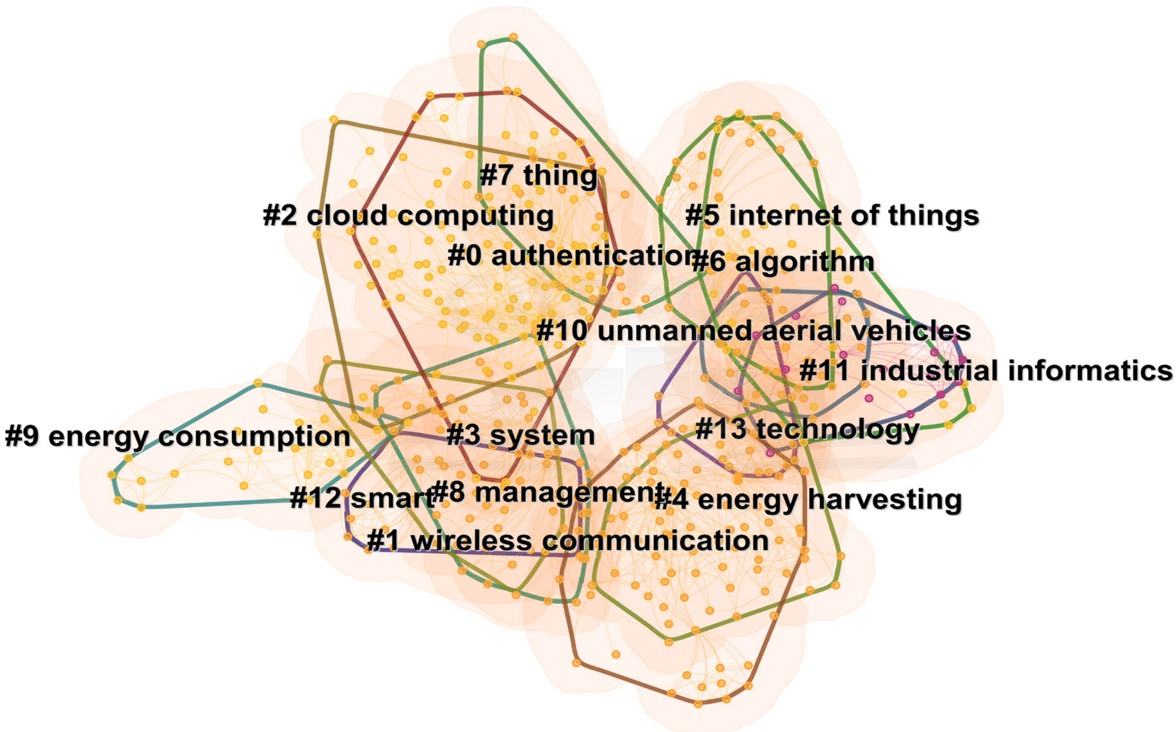

Figure 1. Visualization of cluster analysis of keyword co-occurrence related to IoT.

Source: Web of Science

According to the results of CiteSpace, the centrality of the system, wireless sensor network, and challenge (excluding the internet of things) exceeded 0.1 among the top 20 keywords with high frequency. IoT has many broad applications, many of which are used in a variety of systems, including power systems, agricultural systems, manufacturing systems, assessment control systems, and so forth (de Arquer Fernández et al., 2023; Gzar et al., 2022; Wang et al., 2022; Wang et al., 2022). Additionally, the concept of the system of systems (SoS) is introduced (Pardo et al., 2022) and in fact, several authors have already argued that IoT presents several characteristics of SoS (Lukkien, 2016). A typical Wireless Sensor Network (WSN) integrates wireless communication and integrated sensing devices to track and gather data about a particular area's physical conditions such as humidity, pressure, and temperature. There are two types of communication amongst nodes: logical and actual. WSNs are well recognized for providing quick and cost-effective solutions for applications in the military, business, and health sectors as well as in the environment and cities (Panahi & Bayılmış, 2023). WSN is typically a technology within an IoT system. WSN node connectivity to the internet boosts intelligent online applications and improves user benefit. All heterogeneous devices in an IoT network can gather, send, and receive data as well as transfer it to the internet (Liazid et al., 2023). IoT is made up of WSN, any item, the internet, and online applications. Despite the rapid growth of IoT in several sectors, there are still significant challenges because of interchanging the data, such as security, reliability, privacy, and other considerations. The IoT development faces many security, trust, and infrastructure challenges. The aforementioned challenges must be addressed for the IoT to be accepted and fully deployed. Security issues, such as privacy, authorization, verification, access control, system configuration, information storage, and management, are the main challenges in an IoT environment (Ravikumar et al., 2022). Besides, issues of interoperability, standardization, scalability, and dependability are also essential (Srivastava & Pandey, 2022; Xu, Wang, et al., 2024).

Cluster analysis is performed and the results are shown in Figure 1 with $Q = 0.6658$ and $S = 0.8342$. The top five clusters are Cluster 1 wireless communication, Cluster 2 cloud computing, Cluster 3 system, Cluster 4 energy harvesting, and Cluster 5 internet of things. Energy harvesting provides an attractive solution for IoT applications such as low-power wireless sensor systems, enabling fully wireless devices to be deployed, requiring little or no maintenance. However, these devices generally still need a rechargeable battery or a supercapacitor to meet peak power demands. Energy harvesting designates a technology intended to capture energy from the environment (or human activity) to be able to then operate an electronic device. Like renewable energies, energy harvesting enhances the energy sources naturally present in our environment (Ouafiq et al., 2022). Cloud computing plays a critical role in modern society and enables a range of applications from infrastructure to social media. Such systems must cope with varying loads and evolving usage reflecting societies' interaction and dependency on automated computing systems whilst satisfying Quality of Service (QoS) guarantees (Gill et al., 2019).

Burst detection denotes that nodes appear to rise and fall at a certain period, and the keyword grows suddenly and attracts high attention during this period. The research hotspots that researchers focus on in different years are different, and Table 2 shows the burstiness analysis of keywords about IoT. The results of bursts can be analyzed from these three dimensions the beginning year, strengths, and duration. Sorted by the beginning year of the burst, the top three ranked keywords are sensor network, web, and implementation. Sorted by strengths of burst, the top three ranked keywords are sensor network, web, and data model. Sorted by the duration of the burst, the top three ranked keywords are sensor network, web, and implement. Thus, the sensor network and web should be paid attention to.

Table 2. Top 10 keywords with the strongest citation bursts related to IoT.

Keywords	Year	Strength	Begin	End	2013 - 2023
sensor network	2013	31.37	2013	2018	
web	2013	28	2013	2018	
implementation	2014	20.79	2014	2019	
game theory	2015	21.27	2015	2019	
mobile	2013	18.9	2017	2020	
channel	2018	19.84	2018	2019	
5g mobile communication	2020	19.28	2020	2021	
data model	2020	22.99	2021	2023	
logic gate	2021	19.44	2021	2023	
intrusion detection system	2021	18.48	2021	2023	

Source: Web of Science

Table 3. Top 10 countries ranked by total link strength related to IoT.

Country	Documents	Citations	Total link strength
China	8340	133863	6022
USA	2715	89539	3200
Saudi Arabia	3010	40076	2765
England	1338	34795	2215
Pakistan	1010	14376	1897
South Korea	1973	31326	1781
Australia	1067	34100	1498
Canada	996	23142	1449
Italy	911	29273	887
Spain	843	15191	827

Source: Web of Science

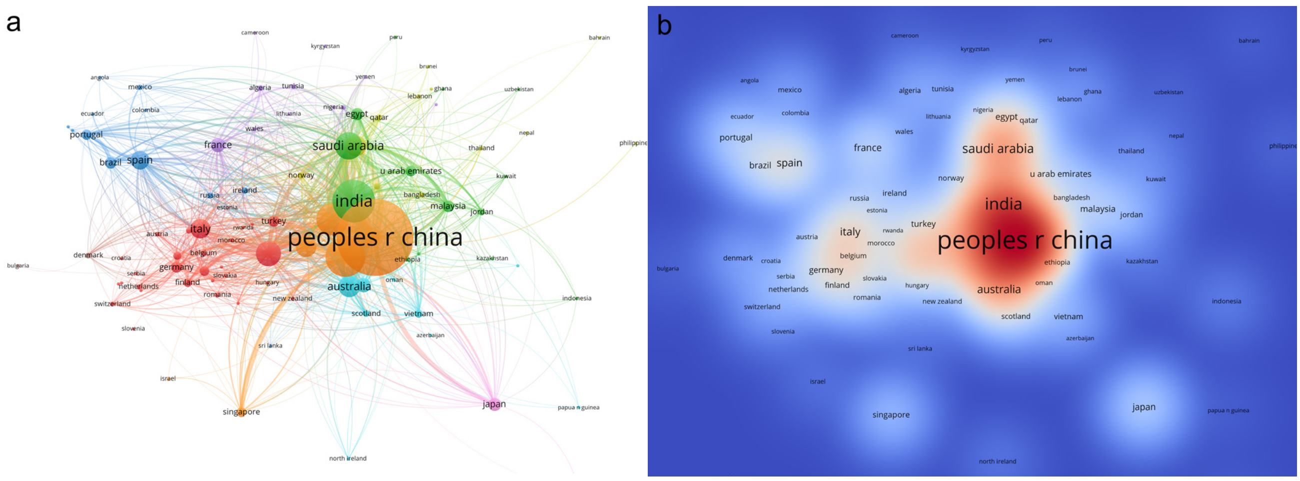

Figure 2. a. IoT co-country network visualization; b. IoT co-country density visualization.
Source: Web of Science

Figure 2 above displays a map of the co-country and the top ten ranked by total link strength (TLS) are listed in Table 3. The minimum number of documents in a country is five, and of the 137 countries, 98 meet the thresholds and form 9 clusters. As shown in Figure 2(a), the number of documents is reflected by the size of bubbles, and link strength is reflected by the thickness of lines. China, the USA, and Saudi Arabia rank top three concerning the number of documents, indicating these countries or researchers in these countries have paid significant attention to IoT. By examining the links, it can be found that the USA has the closest collaboration with China, followed by England, Australia, Canada, India, and South Korea, etc. The four main clusters formed in Figure 2(a) include the orange cluster led by China and the United States, the green cluster led by India and Saudi Arabia, the red cluster led by England and Italy, and the blue cluster led by Australia and Iran. Density visualization in Figure 2(b) is interpreted by the font size, the background of countries, and the density color used to define TLS. The order of sequence is TLS of red > white > blue. The distance between each country hints at how close the collaboration is.

This paper will further answer the following questions:

1. What are the applications of IoT in NEVs and how does IoT help to build smart cities?
2. What is the current status of NEVs and CI in China?
3. What roles of government in promoting NEVs?
4. What are the challenges of using IoT to develop NEVs via case studies discussion?

4. IoT Application Scenarios

Over the decade leading up to 2030, the installed base of IoT connections will expand quickly. Figure 3 illustrates the splitting of IoT-connected devices from four different dimensions. From a perspective of geography, the number of IoT connections in China has steadily increased and has maintained a certain share in the globe, demonstrating that China's demand for IoT connections in the future will be relatively large and significant in the world (Wang et al., 2021). Europe and North America are also likely to lead in terms of the number of IoT devices. From the standpoint of application, the great majority of IoT connections will be utilized for cross-vertical, which is completely consistent with its name, that is, connecting everything and all fields. On top of that, the most substantial number of IoT connections are identified in the Electricity, Gas, Steam & A/C, and Retail & Wholesale sectors. The former are very significant both in homes and in industrial production. IoT can provide a smarter, more convenient, and more accurate way to manage these appliances. Besides, IoT adoption revolutionizes last-mile delivery with IoT-based parcel lockers, offering flexibility, convenience, and 24/7 accessibility for retailers, e-commerce, logistics, and consumers (Tang et al., 2021). Therefore, IoT will be widely used in these aspects. Regarding the field of communication technology, short-range technologies such as Wi-Fi, Bluetooth, and Zigbee will outnumber other communication technologies in the number of IoT connections by 2030. From 2021 through 2030, these short-term technologies are expected to account for the lion's share of communication technologies (Sneha et al., 2022; Kumar et al., 2023). Consumer internet and media devices are the single greatest use case in terms of the number of IoT-connected devices, accounting for around one-third of all devices globally in 2030. Smart grid (Qays et al., 2023) and connected vehicles are the other two major application cases.

Plus, detailed use cases and applications of IoT are listed in Table 4. Most of the applications revolve around smart cities. According to Duque (2023), IoT and Smart Cities are undergoing constant alteration and evolution toward a new digitalization and digital transformation paradigm due to the exponential increase in data generated in the domains of health, commerce, financial services, science, education, public administration, and society (Xu, Chen, et al., 2024a, 2024b). Although creating a smart city is a multifaceted endeavor, NEVs are pioneers in intelligent transportation.

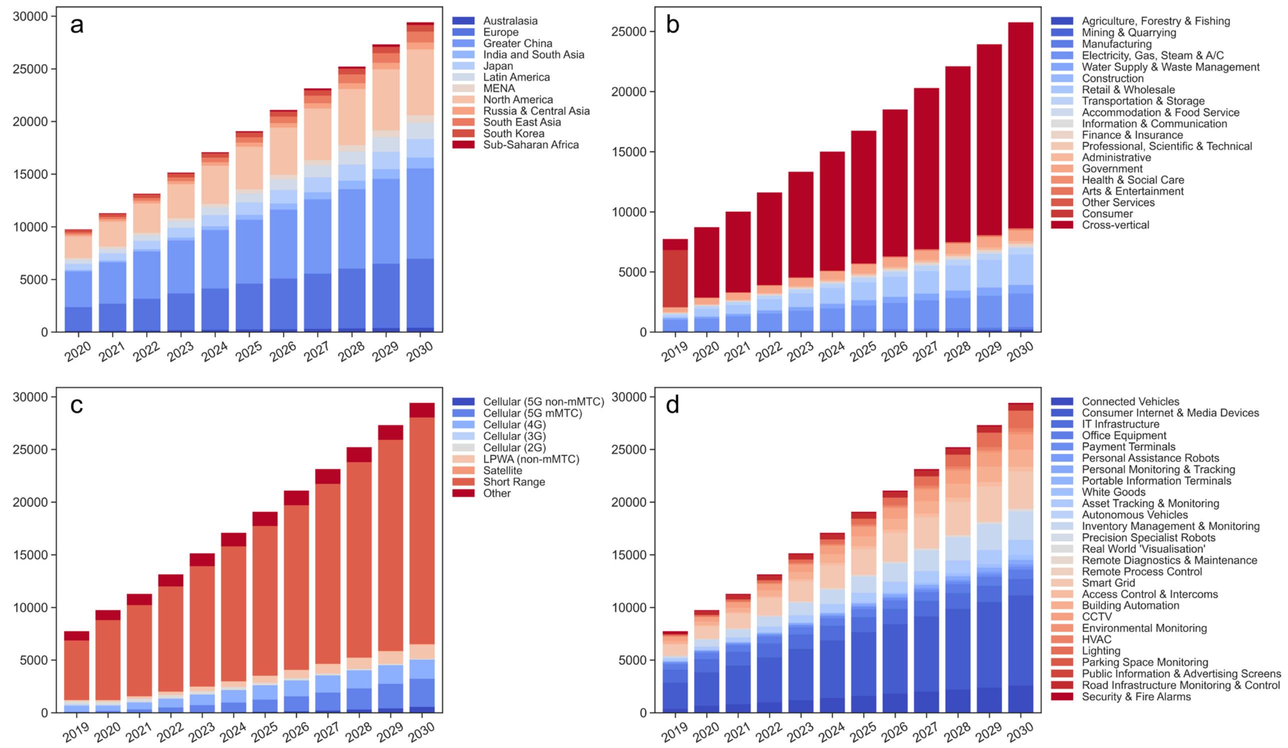

Figure 3. Number of Internet of Things (IoT) connected devices worldwide from 2019 to 2030 (in millions), by region (a), vertical (b), communication technology (c), and use case (d).
Source: Transforma Insights

More specifically, the applications of IoT in NEVs refer to the integration of such components as sensors, gadgets, clouds, and apps into vehicles and their use as a complex system for predictive maintenance, connection of cars, fleet management, etc. (Rahim et al., 2021; Sadeghi-Niaraki, 2023). Based on IoT, Vehicle to Everything (V2X), a new generation communication technology that connects traffic participation factors such as vehicles, roads, people, and cloud as shown in Figure 4, allows vehicles to obtain more information and promotes the innovation and application of autonomous driving technology (Sun et al., 2020). It promotes the development of new vehicle models and traffic services and is significant in improving traffic efficiency, reducing pollution, and accidents, and improving traffic management (Schünemann, 2011). V2X currently covers three typical application scenarios: traffic active safety, traffic efficiency, and information services. The basic application scenarios included are presented in Table 5. These three scenarios are a gradual relationship. The most basic is the scene between a single vehicle and a single vehicle, which is microscopic. The second scenario is macroscopic and focuses more on the overall situation of traffic. The third is to increase basic functions and value-added functions under the premise of ensuring the first two applications. Intuitively, there are more applications in traffic active safety since it is basic.

Table 4. Use cases & applications of IoT.

Use Case	Application Groups
Machine-to-Person	
Connected Vehicles	eCall, Road Fleet Management, In-Vehicle Infotainment, In-Vehicle Navigation, Roadside Assistance, Stolen Vehicle Recovery, Usage-Based Insurance, Vehicle Diagnostics, Vehicle Head Unit, Vehicle Rental, Leasing & Sharing Management, Road Public Transport, Air Transport, Sea & River Transport, Rail Transport
Consumer Internet & Media Devices	Personal Portable Electronics, Smart Home, AV Equipment
IT Infrastructure	IT Infrastructure

Office Equipment	IT Equipment, Other Office Equipment
Payment Terminals	ATMs, Payment Processing, Vending Machines
Personal Assistance Robots	Personal Assistance Robots
Personal Monitoring & Tracking	Child & Pet Tracking, Security Tracking, Assisted Living, Healthcare Monitoring, Worker Safety, Telemedicine
Portable Information Terminals	Portable Information Terminals
White Goods	White Goods
Autonomous Systems	
Asset Tracking & Monitoring	Asset Monitoring, Bike Sharing, Container Tracking, Loss Prevention, Track & Trace, Waste Management
Autonomous Vehicles	Autonomous Road Vehicles, Drones, Retail Delivery Robots
Inventory Management & Monitoring	Inventory Management & Monitoring
Precision Specialist Robot	Precision Specialist Robot
Remote Diagnostics & Maintenance	Remote Diagnostics & Maintenance
Remote Process Control	Remote Process Control
Real World 'Visualization'	Connected Glasses
Smart Grid	Generation, Grid Operations, Electric Vehicle Charging, Electricity Smart Meters, Gas Smart Meters, Water Smart Meters
Smart Environment	
Access Control & Intercoms	Access Control & Intercoms
Building Automation	Building Automation
CCTV	CCTV
Environmental Monitoring	Agriculture, Environment Monitoring, Infrastructure Monitoring
HVAC	HVAC
Lighting	Building Lighting, Public Space Lighting
Parking Space Monitoring	Parking Space Monitoring
Public Information & Advertising Screens	Public Information & Advertising Screens
Road Infrastructure Monitoring & Control	Road Traffic Control, Road Traffic Monitoring
Security & Fire Alarms	Security & Fire Alarms

Source: Transforma Insights

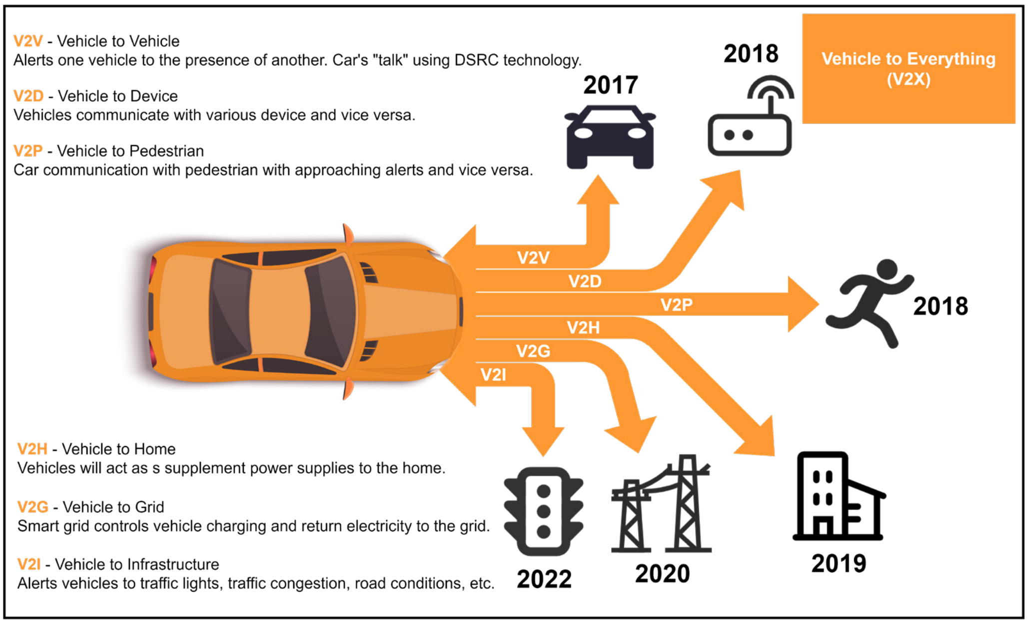

Figure 4. V2X application diagram.

Table 5. Typical V2X application scenarios.

Scenarios	Applications
Active traffic safety	forward collision warning, left turn assist/alarm, incoming main road assist/collision alarm, intersection collision alarm (with signal light/no signal light/no visual range, etc. with the roadside unit), intersection collision alarm (with signal light/no signal light/no visual range, etc. without road units), overtaking auxiliary/reverse overtaking remind/through overtaking, blind spot alerting/auxiliary lane changing, emergency brake alerting (emergency electronic brake lights), the vehicle safety function is out of control alarm, abnormal vehicle alarm (including static/slow vehicles ahead), stationary vehicles remind (such as traffic accident, vehicle failure cause), non-motor vehicles (electric cars, Bicycle, etc.) crossing alerting /pedestrian crossing alerting, emergency vehicle alerting, slippery/dangerous road alerting (wind, fog, ice, etc.), red light (/ yellow light) alarm)
Traffic efficiency	deceleration zone/speed limit reminder (tunnel speed limit, general speed limit, curve speed limit, etc.), speed guidance, car signs, electronic charging without parking
Information services	entrance payment, automatic parking guidance and control, SOS/eCALL service, vehicle theft/damage (including whole vehicles and parts) alarm, remote vehicle diagnosis, maintenance tips

Source: Ecotron

5. Current Status of NEVs in China

A comparison of new energy vehicle ownership in 20 selected countries shown in Figure 5 indicates that NEVs are increasing all around the globe and China has a major proportion. According to MIIT of China, in 2022, China's new energy vehicle production and sales reached 7,058,000 and 6,887,000 respectively, up 96.9% and 93.4% year-on-year, with a market share of 25.6%. Sales and growth rates are presented in Figure 6. In the month of December 2022, the production and sales of new energy vehicles reached 795,000 and 814,000 respectively, with a year-on-year growth of 51.8%. Among the main varieties of new energy vehicles, the production and sales of pure electric vehicles, plug-in hybrid vehicles, and fuel cell vehicles continued to maintain high growth (Wang, 2023). According to the statistics of the Ministry of Public Security of China, the number of new energy vehicles in China reached 13.1 million, accounting for 4.10% of the total number of vehicles, a year-on-year increase of 67.13%, suggesting a rapid growth trend (Li, 2023). Besides, Nancy W. Stauffer (2021) predicts that by 2030, 40 percent of vehicles sold in China will be electric. Based on the above, it can be concluded that NEVs in China gradually entered the full market expansion period.

The top 10 new energy vehicle brands in 2022 in China are listed in Table 6. From the table, it can be seen that three of the 10 brands are from Guangdong which reflects Guangdong's strength in new energy vehicle manufacturing. Figure 7 illustrates the number of sales and sales amount for the top five brands. It can be seen that BYD's sales volume is basically in the first and much higher than Tesla in China, suggesting that BYD has more heat of attention than Tesla and is highly competitive internationally (He & Hao, 2023; Yang et al., 2022; Gao & Kwok, 2024).

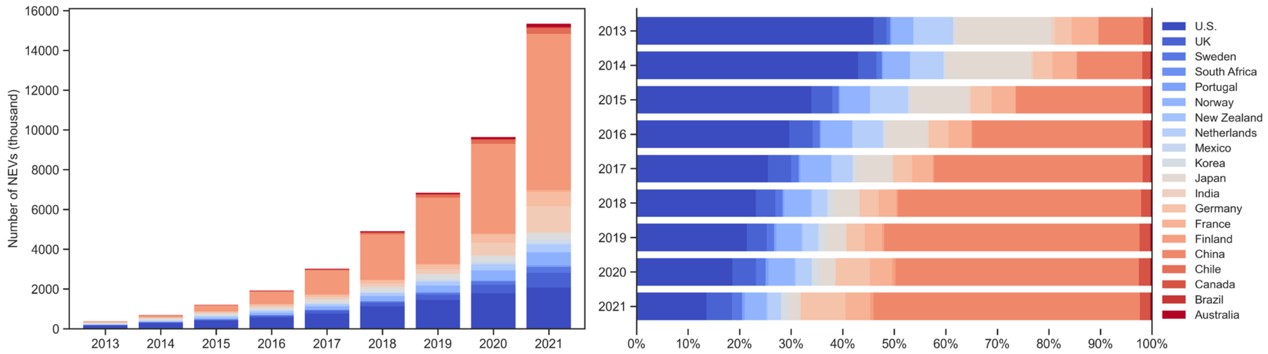

Figure 5. The ownership of new energy vehicles in the selected 20 countries.
Source: www.iea.org

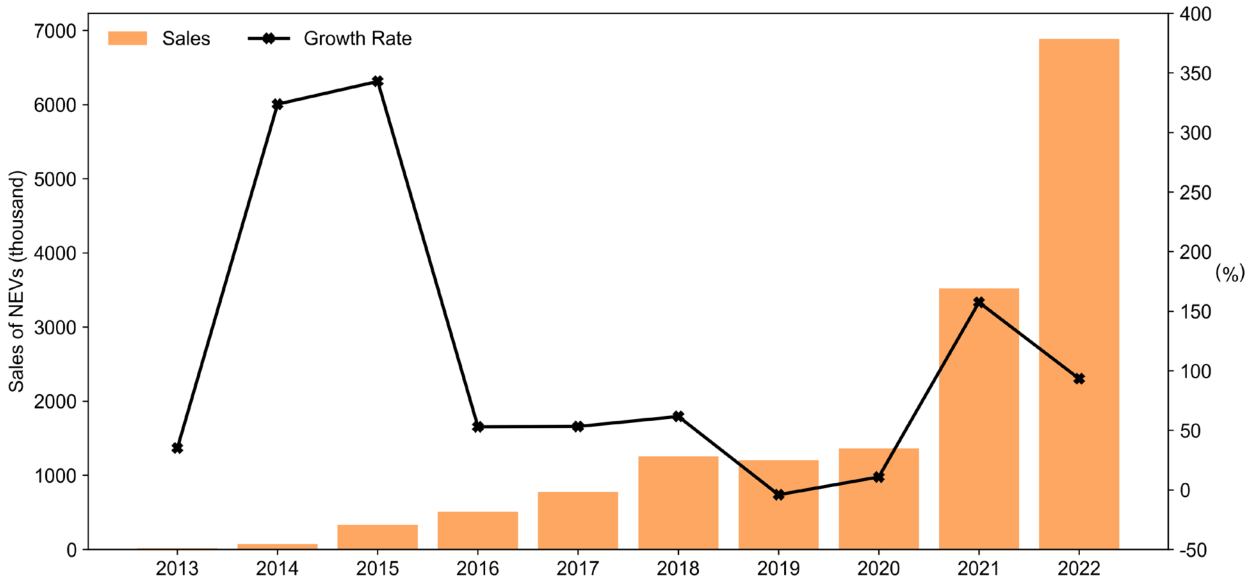

Figure 6. New energy vehicle sales and growth rate from 2013 to 2022.
Source: China Association of Automobile Manufacturers (CAAM)

Table 6. Top 10 new energy vehicle brands in 2022 in China.

Rank	Brand	Year of Establishment	Cradle
1	Tesla	2003	USA
2	NIO	2015	Hefei, Anhui
3	BYD	1995	Shenzhen, Guangdong
4	XPENG	2014	Guangzhou, Guangdong
5	LI	2015	Beijing
6	BWM	1916	Germany
7	AION	2017	Guangzhou, Guangdong
8	NETA	2018	Shanghai
9	ZEEKR	2021	Ningbo, Zhejiang
10	AITO	2021	Chongqing

Source: www.maigoo.com

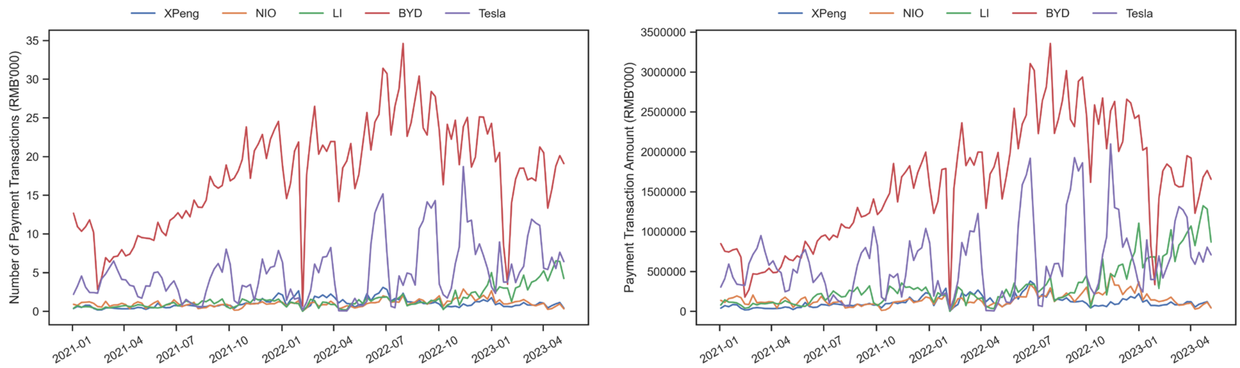

Figure 7. The number and amounts of transactions of the top five new energy vehicle brands.
Source: www.datayes.com

Figure 8 displays the situation of public charging posts in the 20 countries that were selected. From the figure, it can be seen that the number of public charging posts worldwide is steadily increasing year by year, and China has a very large share in the world. Figure 9 shows the growth in the number of public charging posts in China, split between DC (fast charging) and AC (slow charging). As Jeong et al. (2023) suggest, recently, tremendous efforts have been devoted to searching for the fast-charging methodology of lithiumion batteries. Hence, DC is the future of charging infrastructure.

Figure 10 exhibits the heat map of charging infrastructure by province. Charging infrastructure is mainly divided into public charging posts, shared private charging posts, public charging stations, and switching stations. Guangdong has the darkest color on the map, which means that this province has the most charging facilities. In addition, there are relatively more charging facilities in Shanghai, Jiangsu, Zhejiang, and Beijing. To illustrate these cities' charging infrastructure components, Figure 11 plots the number of charging facilities separably of five top cities in recent years. It is worth noting that in terms of public charging vehicles and charging stations, Guangdong has the largest number, indicating Guangdong has attached great emphasis on charging infrastructure development.

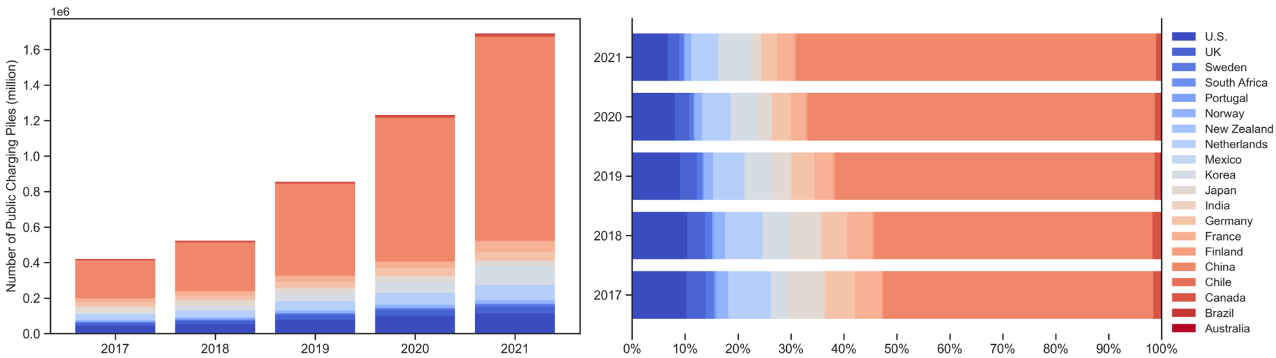

Figure 8. Number of public charging piles in selected 20 countries.
Source: www.iea.org

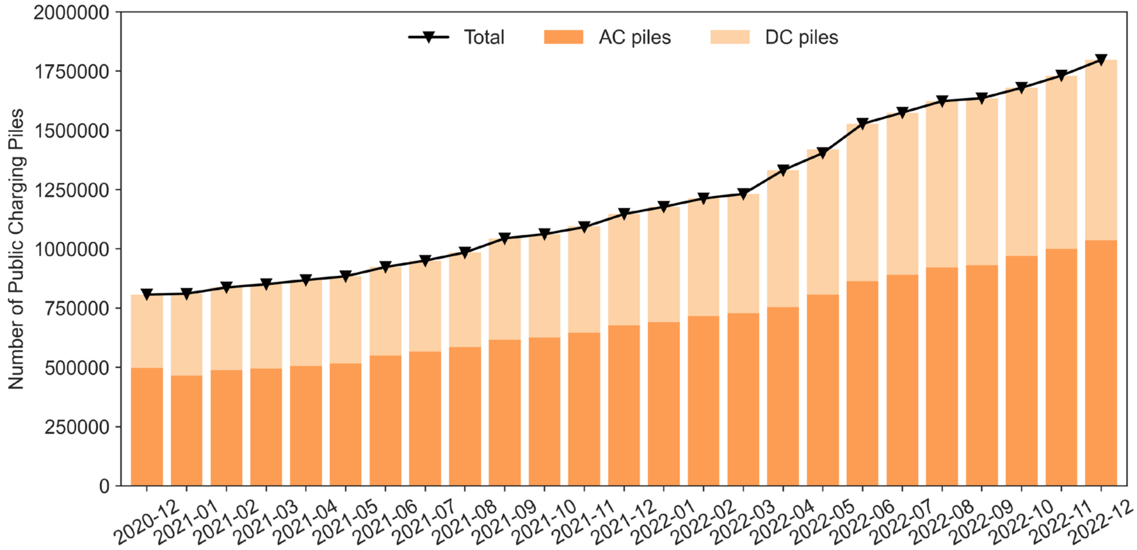

Figure 9. Number of public charging piles in China (DC and AC).
Source: www.evcipa.org.cn

Figure 10. Heat map of charging infrastructure by province
Source: www.evcipa.org.cn

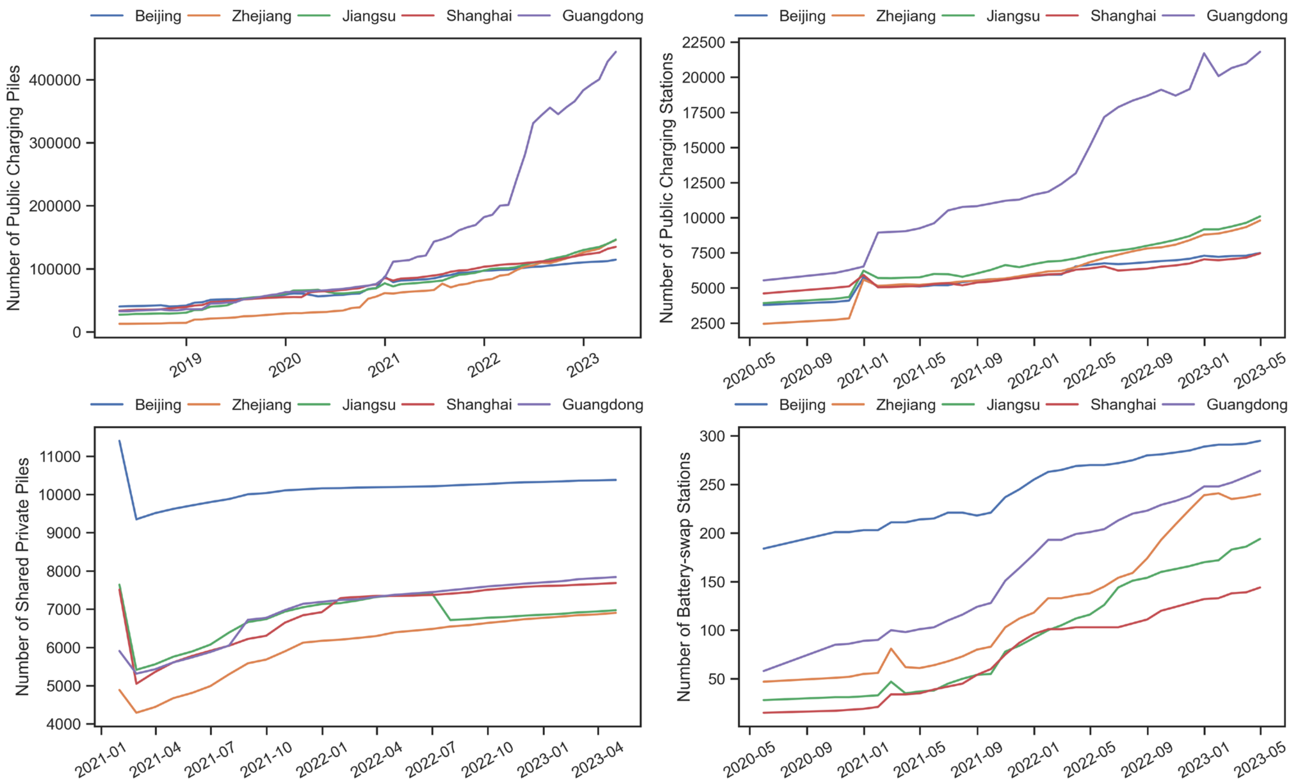

Figure 11. Number of public charging piles, public charging stations, shared private piles, and switch stations. Source: www.evcipa.org.cn

6. Government Roles in Promoting NEV in China

The development of new energy vehicles in China cannot be achieved without the support of government policies at all levels (Hsiao et al., 2023; Pei et al., 2023) because it may be challenging for the industry to address these pressures through the efforts of NEV enterprises alone (Siddiqui et al., 2007). In this section, this paper collects the various policies at the national level for new energy vehicles over the last ten years and briefly summarizes their general central meaning. In addition, this paper analyses the changing characteristics of these policies, examining how they differ at different stages of development in China and how they have helped the development of new energy vehicles.

The Chinese government's support for the NEV industry can be traced back to critical technical projects for electric vehicles covered in the "Eighth Five-Year Plan" period. The New Energy Vehicle Pilot City (NEVPC) policy launched in 2009 is a landmark move by the Chinese government to elevate the strategic importance of the country's NEV industry at a national level. This government subsidy policy for China's NEV industry has now gone through two full five-year planning periods. Besides, since 2009, the related subsidy policy has been changing with the development of the industry, from the pilot demonstration and promotion stage to the promotion and application stage, and then to the market-oriented adjustment stage; the geographical scope has developed from the pilot cities to the national scope, and the subsidized models have changed from only subsidized public vehicles to various new energy models. According to the latest subsidy policy, the subsidy for new energy vehicles will be terminated in 2022. A summary of the history of policy is reported in Table 7.

For more than 30 years, the Chinese government's innovation policy for the NEV industry has covered various aspects of emerging industries ranging from technology research and development (Zuo et al., 2019) to commercialization (Zhao et al., 2018). The policy plan for China's new energy vehicle industry involves an acquisition subsidy policy, energy conservation and emission reduction policy, battery charging pile supporting industry policy, etc., which are summarized in Table 8. According to Jiang & Xu (2023), these policies and incentives can be classified as financial aid, subsidized conditions, and financing convenience and together they can promote enterprise technology innovations. Likewise, Wang & Liao (2023) classify these policies into non-reimbursable subsidies, loan interest subsidies, and incentives, suggesting they can promote the popularization of NEVs and improve industrial competitiveness.

In October 2020, the State Council issued the "New Energy Vehicle Industry Development Plan (2021-2035)", proposing that the development of new energy vehicles is the only way for China to move from a large automobile country to a strong automobile country, and is a strategic initiative to address climate change and promote green development. Table 9 interprets this plan in detail. In addition to national-level policies, China's 34 provinces and cities have also issued local policy plans for the new energy vehicle industry, involving expected targets for output value, industry support for development, etc., and are listed in Table 10.

Table 7. History of Policy.

	Pilot Demonstration Extension Stage		**Promotion of Application Stage**	**Market-based Adjustment Phase**
Time Nodes	2009	2010-2012	2013-2017	2018-2022
Core Policy	*Notice on the Commencement of the Pilot Work of Demonstration and Promotion of Energy-saving and New Energy Vehicles*	*Notice on the Development of Private Purchase of New Energy Vehicles Subsidies Pilot*	*Notice on the Continuation of the Promotion and Application of New Energy Vehicles, Notice on Further Work on the Promotion and Application of New Energy Vehicles*	*Notice on Adjusting and Improving the Financial Subsidy Policy for the Promotion and Application of New Energy Vehicles, Notice on the Financial Subsidy Policy for the Promotion and Application of New Energy Vehicles in 2022*
Promotional scope	13 pilot cities	6 pilot cities	88 pilot cities	Nationwide
Subsidized Models	Public service vehicles	Private Purchase of Vehicles	NEV of all types	NEV of all types

Source: authors' elaboration

Table 8. Summary of national-level new energy vehicle industry policies.

Date	**Authority**	**Title**	**Main Implications**
2012.6.28	State Council	*Energy-saving and New Energy Vehicle Industry Development Plan (2012-2020)*	Accelerate the promotion and application and pilot demonstration, and actively promote the construction of charging facilities.
2014.07.21	Office of the State Council	*Guidance on Accelerating the Promotion and Application of New Energy Vehicles*	Accelerate the construction of charging facilities and actively guide enterprises to innovate business models. Promote the public service sector to take the lead in promoting the application.
2015.05.08	State Council	*Made in China 2025*	Develop electric and fuel cell vehicles, master low-carbon and intelligent technologies, and form a complete industrial system and innovation system.
2017.04.06	MIIT, NDRC, MOST	*Medium- and Long-term Development Plan for the Automobile Industry*	Accelerate the development and industrialization of new energy vehicle technology.
2018.11.09	NDRC, NEA, MIIT, MOF	*Action Plan for Enhancing the Charging Guarantee Capability of New Energy Vehicles*	Accelerate the improvement of the charging standard system, optimize the layout of charging facilities comprehensively, and significantly enhance the interconnection and interoperability of the charging network.
2019.05.08	MOF, MIIT, MOT, NDRC	*Notice on Supporting the Promotion and Application of New Energy Buses*	Implement the policy of exempting new energy buses from vehicle purchase tax and vehicle tax.
2020.04.16	MOF, SAT, MIIT	*Notice on the Policy of Exemption from Vehicle Purchase Tax for New Energy Vehicles*	From January 18, 2021, to December 31, 2022, the purchase of new energy vehicles is exempt from vehicle purchase tax.
2020.09.26	MOF, MIIT, MOST, NDRC,	*Notice on the Demonstration and Application of Fuel Cell Vehicles*	Give incentives to eligible city groups to carry out the in-

	NEA		dustrialization of key core technologies for fuel cell vehicles and demonstration applications.
2020.10.20	Office of the State Council	*Development Plan for New Energy Vehicle Industry (2021-2035)*	China's new energy vehicle market competitiveness by 2025 will be enhanced by breakthroughs in key technologies, including highly self-driving vehicles for limited commercial applications and charging and switching services for improved convenience.
2021.2.22	State Council	*Guiding Opinions on Accelerating the Establishment of a Sound Green Low-Carbon Circular Development Economic System*	Actively build green highways, green railroads green waterways, green ports, and green airports. Strengthen the construction of supporting infrastructure for new energy vehicle charging and switching, hydrogen refueling, etc.
2021.03.13	NDRC	*Outline of the Fourteenth Five-Year Plan for National Economic and Social Development of the People's Republic of China and the Vision 2035*	Accelerate the application of key core technology innovation, enhance the ability to guarantee the elements, and cultivate and grow new momentum for industrial development.
2021.04.30	MIIT, MOF, SAT	*Announcement on the Adjustment of Technical Requirements for New Energy Vehicle Products Exempted from Vehicle Purchase Tax*	Plug-in (including add-on) hybrid passenger vehicles with pure electric range should meet the conditions of the equivalent full electric range of not less than 43 kilometers.
2021.08.19	MIIT, MOST, MEE, MOC, SAMR	*New Energy Vehicle Power Battery Gradient Utilization Management Measures*	Strengthen the management of new energy vehicle power battery gradient utilization, to protect the quality of gradient battery products.
2021.08.23	SAMR	*Announcement on the Regulation of New Energy Vehicle Testing Fees*	The motor vehicle testing agencies should be based on the structural characteristics of new energy vehicles, the establishment of real and reasonable testing charges, and set out the service content, so that the price is marked as honest business.
2021.10.24	State Council	*Carbon Peak Action Plan by 2030*	Promote low-carbon transformation of transportation equipment, vigorously promote new energy vehicles, and gradually reduce the proportion of traditional fuel vehicles in new vehicle production and sales and car ownership.
2021.12.09	State Council	*"Fourteenth Five-Year Plan" Modern Comprehensive Transportation System Development Plan*	Steady progress in the construction of green transportation and safe transportation, with new energy vehicles accounting for more than half of the global total.
2021.12.12	State Council	*"Fourteenth Five-Year Plan" Digital Economy Development Plan*	Improve the supply chain system of key industries such as 5G, integrated circuits, new energy vehicles, artificial intelligence, industrial Internet, etc.
2021.12.14	State Council	*"Fourteenth Five-Year Plan for the Modernization of Market Supervision*	Strengthen recall management for key products like passenger trucks, energy vehicles, smart homes, children's products, and electronic appliances by improving defective product recall systems.
2021.12.25	Office of the State Council	*Promote Multimodal Development to Optimize the Adjustment of Transport Structure Work Program (2021-2025)*	With significant optimization of the transport structure of key regions, the main coastal ports using the harbor-clearing railroads, waterways, and closed belt corridors, the proportion of new energy vehicles to transport bulk cargo strives to reach 80%.
2021.12.28	State Council	*"Fourteenth Five-Year Plan" Comprehensive Work Plan for Energy Saving and Emission Reduction*	Increase the proportion of new energy vehicles used in urban public transport, rental, logistics, sanitation, and cleaning vehicles.
2021.12.31	MOF, MIIT, MOST, NDRC	*Notice on the Financial Subsidy Policy for the Promotion and Application of New Energy Vehicles in 2022*	The 2022 new energy vehicle purchase subsidy policy will end on December 31, 2022, and vehicles licensed after December 31, 2022, will no longer be subsidized.
2022.01.10	NDRC	*Implementation Opinions on Further Improving the Service Guarantee Capability of Electric Vehicle Charging Infrastructure*	Promote pilot demonstrations, explore new energy vehicle implementation in electricity spot markets, and improve trading and dispatching mechanisms for green electricity consumption and storage.
2022.05.31	State Council	*A Package of Policy Measures to Solidly*	Optimize the investment and construction operation mode

		Stabilize the Economy	of new energy vehicle charging piles and charging stations, and accelerate the construction of charging facilities in highway service areas, passenger transportation hubs, and other areas.
2022.08.25	MOT, NEA, SGCC, CSG	*Action Plan for Accelerating the Construction of Charging Infrastructure Along Highways*	Strive for the end of December 2022, the completion of the highway charging infrastructure construction tasks. 2023 by the end of December, the completion of ordinary state and provincial highway charging infrastructure construction.
2022.10.08	NDRC, NEA	*Guiding Opinions on Implementing Rural Power Grid Consolidation and Upgrading Project (Draft for Comments)*	Do a good job of rural charging infrastructure supporting the construction of power grids, service electric vehicles to the countryside.
2022.10.24	MOT, NRA, CAAC, SPB	*Opinions on Accelerating the Construction of the Main Skeleton of the National Comprehensive Three-Dimensional Transportation Network*	Promote the electrification of railroads and the electrification of airport operations, and accelerate the effective coverage of highway fast-charging networks.
2022.12.14	State Council	*Outline of the Strategic Plan for Expanding Domestic Demand (2022-2035)*	Optimize urban transportation networks and develop intelligent transportation by promoting electrification, networking, and automobile intelligence, while strengthening parking, charging, and switching facilities.
2022.12.15	Office of the State Council	*"Fourteenth Five-Year Plan" Modern Logistics Development Plan*	Accelerate the application of new energy, emission standards, and other freight vehicles in the field of modern logistics, especially urban distribution.
2022.12.15	NDRC	*"Implementation Plan for the 14th Five-Year Plan for Expanding Domestic Demand Strategy"*	Strengthen the construction of parking lots, charging piles, exchange stations, hydrogen refueling stations, and other supporting facilities.

Source: www.most.gov.cn; www.mof.gov.cn; www.gov.cn; www.miit.gov.cn

Table 9. Interpretation of the New Energy Vehicle Industry Development Plan (2021-2035).

Main tasks	Content
Strengthen the whole vehicle integration technology innovation	An innovation chain for vehicle technology includes pure electric, plug-in hybrid, and fuel cell vehicles. Research is being done on a high-performance platform, multi-energy systems, energy management, and safety technologies to enhance the performance of new energy vehicles.
Build a new industrial ecology	Encourage cross-border synergy among enterprises in energy, transportation, information and communication, and new energy vehicles. Build ecologically dominant enterprises covering key industry chains links like solutions, R&D, production, usage guarantee, and operation services. Foster new energy vehicle industry clusters through upstream-downstream collaboration, international competitiveness, and modernizing the industry chain.
Enhance intelligent manufacturing	Promote intelligent technology in new energy vehicle R&D design, manufacturing, warehousing and logistics, management, after-sales service, and other key aspects of the depth of application. Accelerate the development and integration of core industrial software for simulation, management, and control of intelligent manufacturing of new energy vehicles, and carry out demonstration of intelligent factories and digital workshops.
Reinforce quality and safety assurance	Carry out new energy vehicle product quality improvement action, guide enterprises to strengthen the design, manufacturing, testing, and verification of the whole process of reliability technology development and application, improve the new energy vehicle, parts and maintenance testing, charging and switching and other safety standards and regulatory system, strengthen the supervision and management of safety production and new energy vehicle safety recall management.
Promote the development of industrial integration	Strengthen the energy interaction between new energy vehicles and power grids (V2G), and promote efficient synergy between new energy vehicles and renewable energy. Promote information sharing and integration of new energy vehicles with meteorological and renewable energy power forecasting systems, coordinate energy utilization of new energy vehicles with wind power generation and photovoltaic power generation, and enhance the proportion of renewable energy applications.

Source: www.gov.cn

Table 10. Summary of new energy vehicle industry policies in 34 provinces and cities.

Province	Date	Title
Guangdong	2020.09	*Guangdong Province Action Plan for the Development of Strategic Automotive Pillar Industry Clusters (2021-2025)*
	2021.12	*The 14th Five-Year Plan for the Development of Electric Vehicle Charging Infrastructure in Guangdong Province*
Shanghai	2021.02	*Implementation Plan for Accelerating the Development of New Energy Vehicle Industry in Shanghai (2021-2025)*
	2022.10	*Shanghai Transportation Development White Paper*
Anhui	2021.06	*Action Plan for the Development of New Energy Vehicle Industry in Anhui Province (2021-2023)*
	2022.06	*Anhui Province Charging Infrastructure Construction "Fourteen Five" Plan*
Zhejiang	2021.04	*Fourteenth Five-Year Plan for the Development of New Energy Vehicle Industry in Zhejiang Province*
Jiangsu	2021.11	*Jiangsu Province "Fourteenth Five-Year Plan" for the Development of New Energy Vehicle Industry*
Chongqing	2021.09	*Chongqing's 14th Five-Year Plan for High-Quality Development of Manufacturing Industry (2021-2025)*
	2022.07	*City-wide Work Plan to Accelerate the Construction of Charging and Switching Infrastructure*
Sichuan	2021.03	*Sichuan Province "14th Five-Year Plan" and the Outline of the 2035 Vision*
	2022.03	*Sichuan Province "14th Five-Year Plan" Energy Development Plan*
Beijing	2022.08	*Beijing New Energy Vehicle Charging and Switching Facilities Development Plan for the "14th Five-Year Plan" Period*
Tianjin	2021.09	*Tianjin New Energy Industry "14th Five-Year Plan"*
	2022.07	*Notice on the Issuance of the 2022 New Energy Vehicle Charging Infrastructure Work Points*
Hebei	2020.07	*Three-Year Action Plan for the Development of Automotive Industry Chain Clusters in Hebei Province (2020-2022)*
	2022.04	*Implementation Opinions on Accelerating the Enhancement of Charging Infrastructure Service Guarantee Capability*
Shandong	2018.05	*Medium- and Long-term Development Plan of Shandong Province Automobile Industry (2018-2025)*
	2022.07	*Shandong Province Electric Vehicle Charging Infrastructure "Fourteen Five" Development Plan*
Guangxi	2021.10	*Guangxi New Energy Vehicle Charging Infrastructure Planning (2021-2025)*
	2021.12	*Guangxi Province New Energy Vehicle Industry Development "Fourteen Five" Plan*
Yunnan	2021.11	*Yunnan Province New Energy Vehicle Industry Development Plan (2021-2025)*
	2022.04	*The 14th Five-Year Plan for Regional Coordinated Development of Yunnan Province*
Fujian	2022.04	*Development Plan for New Energy Vehicle Industry in Fujian Province (2022-2025)*
Jiangxi	2020.11	*Jiangxi Province Three-Year Action Plan for Accelerating the Construction of Electric Vehicle Charging Infrastructure (2021-2023)*
Hubei	2021.05	*Interim Measures for the Construction and Operation of New Energy Vehicle Charging Infrastructure in Hubei Province*
	2022.06	*The 14th Five-Year Plan for Energy Development in Hubei Province*
Hunan	2021.02	*Implementation Opinions on Accelerating the Construction of Electric Vehicle Charging (Switching) Infrastructure*
	2022.03	*Fourteenth Five-Year Plan for the Development of Intelligent Networked Vehicle Industry in Hunan Province (2021-2025)*
Guizhou	2021.11	*Guizhou Province New Energy Vehicle Industry "14th Five-Year Plan" Development Plan*
Shaanxi	2021.05	*Shaanxi Province Electric Vehicle Charging Infrastructure "Fourteenth Five-Year Plan" Development Plan*
Shanxi	2021.05	*Shanxi Province "Fourteenth Five-Year Plan" New Infrastructure Planning*
	2022.01	*Shanxi Province Automotive Mid-Lasting Development Plan*
Henan	2021.11	*Henan Province to Accelerate the Development of New Energy Vehicle Industry Implementation Plan*
Liaoning	2021.04	*Liaoning Province "14th Five-Year Plan" and 2035 Visionary Goals Outline*
	2022.12	*Liaoning Province "14th Five-Year Plan" Electric Vehicle Charging Infrastructure Special Plan*
Heilongjiang	2022.02	*Heilongjiang Province New Energy Vehicle Industry Development Plan (2022-2025)*
Jilin	2022.08	*The 14th Five-Year Plan for Energy Development in Jilin Province*
	2022.11	*Development Plan for Electric Vehicle Charging and Switching Infrastructure in Jilin Province (2021-2025)*
Inner Mongolia	2021.01	*The 14th Five-Year Plan for the Development of Industry and Information Technology in Inner Mongolia Autonomous Region*
Ningxia	2021.12	*The 14th Five-Year Plan for Addressing Climate Change in Ningxia Hui Autonomous Region*
	2022.03	*Ningxia Charging Infrastructure "14th Five-Year Plan*
Qinghai	2021.08	*Implementation Opinions on the Implementation of the National Development Plan for New Energy Vehicle Industry in Qinghai Province (2021-2035)*
Gansu	2022.04	*Implementation Opinions on the Development of New Energy Vehicle Industry in Gansu Province*
	2022.10	*Implementation Plan for the Construction of Charging Infrastructure along Highways in Gansu Province*
Hainan	2019.05	*Hainan Province Electric Vehicle Charging Infrastructure Planning (2019-2030)*
	2020.12	*Proposal of the CPC Hainan Provincial Committee on Formulating the Fourteenth Five-Year Plan for National Economic and Social Development and the Visionary Goals for 2035*

Xinjiang	2022.01	*Guiding Opinions on Further Accelerating the Promotion and Application of New Energy Vehicles and Industrial Development*
Tibet	2022.06	*Implementation Rules on the Implementation of the Package of Policy Measures for Solidly Stabilizing the Economy*
Hong Kong	2021.03	*Roadmap for the Popularization of Electric Vehicles in Hong Kong*
Macau	2022.01	*Macao Environmental Protection Plan (2021-2025)*
Taiwan	2021	*Plan for the Construction and Installation of Public Charging Piles*

Source: provincial government websites

7. The Case of Guangdong Province

Qualitative research is defined as a tool for exploring and comprehending the significance that individuals or groups concentrate on social or human concerns (Yin, 2015; Creswell, 2009; Klein & Myers, 1999). As a consequence, this section adopts a case analysis approach. Guangdong is an important base for China's traditional automobile industry, but in the context of the "double carbon transition" and decarbonization of the transportation sector, the traditional automobile industry is facing the impact of new energy vehicles, and the fuel car town is facing a difficult transition. But in just a decade or so, Guangdong has shifted from a strong traditional auto manufacturing province to a large province of new energy vehicles (Zhou et al., 2023). The pattern of new energy vehicle manufacturing has also developed from a single city in Guangzhou to a three-pronged pattern of Guangzhou, Shenzhen, and Zhaoqing. Besides, Guangdong has become the best province for the development of new energy vehicles in China. Hence, this section covers the current status of new energy vehicle development, relevant policies, and a detailed analysis of the three better-developed cities using the case study method.

Guangdong pays considerable attention to policy support (Shao & Mišić, 2023). Figure 13 illustrates the number of policies issued in Guangdong province by August 26, 2022. During the 11th Five-Year Plan period, Guangdong began to lay out new energy vehicle-related technology research and development and industrialization transformation. In the 12th Five-Year Plan period, the new energy vehicle industry was included for the first time as a key industry in Guangdong's strategic emerging industries and advanced manufacturing industry and became one of the key industries in Guangdong. In 2022, under the background of the "dual carbon strategy", Guangdong Province's new energy vehicle industry development policies continued to increase, and from January to August 2022, Guangdong Province issued 20 policies related to the new energy vehicle industry, exceeding the speed of policy released in 2021. The 14th Five-Year Plan for the High-Quality Development of Guangdong's Manufacturing Industry in 2021 promotes the development of intelligent networked vehicles, and the 2022 Action Plan for Accelerating the Construction of a Fuel Cell Vehicle Demonstration City Cluster in Guangdong Province (2022-2025) aims to build a globally competitive new energy vehicle industry with high technological innovation. All these policies can be found at www.gd.gov.cn. Moreover, Guangdong's forward-looking approach to the development of the new energy vehicle industry is reflected in the "Action Plan for Accelerating the Construction of Fuel Cell Vehicle Demonstration Cities (2022-2025)". In addition to provincial policies, the 21 prefecture-level cities under Guangdong have also issued relevant policies.

Figure 12 depicts the heat map of the smart car industry in Guangdong cities by Southern Metropolis Daily (2021), which divides cities in Guangdong into five levels including 0: No planned layout of automotive industry cities; 1: General cities with planned industrial layout; 2: Important cities with planned industrial layout; 3: Cities with a high degree of heat in the smart car industry; 4: Cities with leading heat in smart car industry. The hierarchical evaluation system includes the policy system, industrial structure, and new infrastructure ecology. Besides, some cities also mentioned relevant industrial planning in the 2021 government work report, revealing the importance attached to the industry and determining the plan. Among them, Guangzhou, Foshan, and Zhaoqing proposed in the government work report that the intelligent network or new energy vehicle industry should be one of the leading industrial clusters for urban development. Relevant policies can be found in zhaoqing.gov.cn, foshan.gov.cn, gz.gov.cn. Nevertheless, from the figure, Guangzhou, Shenzhen, and Zhaoqing rank in the first echelon of heat value (level 4), becoming the cities with the strongest momentum for industrial development.

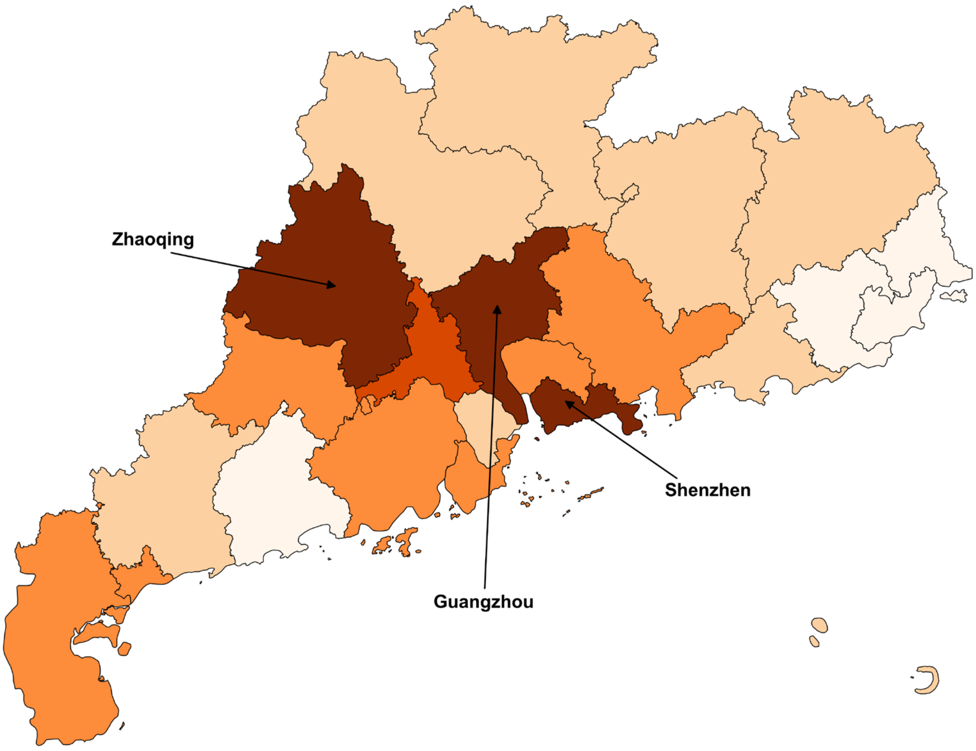

Figure 12. Heat map of the smart car industry in cities in Guangdong.
Source: www.nandu.com

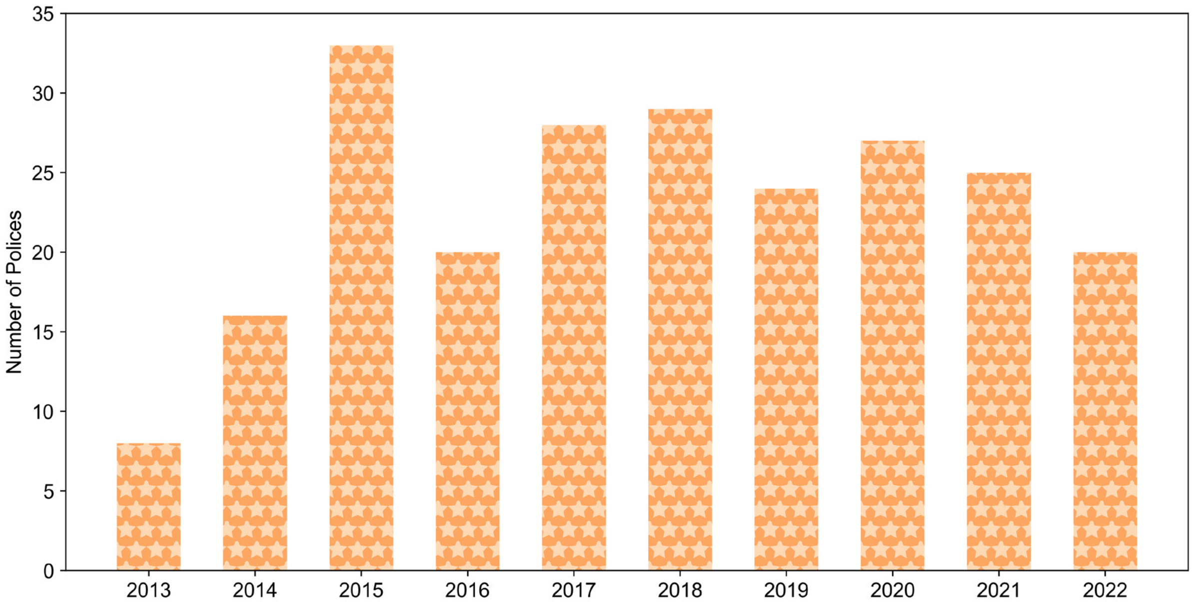

Figure 13. 2013-2022 Trends in the number of policies related to the NEV industry in Guangdong Province.

Source: www.djyanbao.com

Note: The statistics of the above policies are as of August 26, 2022

7.1. Guangzhou: City of Smart Cars and Capital of Supercharging

Guangzhou is renowned as one of China's foremost automobile production hubs. Its auto industry cluster is focused on constructing an intelligent network-linked automobile industry chain, which is IoT technology, with vehicle manufacturing at its core. This cluster also draws together parts and components of enterprises, as well as high-tech innovation companies.

Presently, Guangzhou has developed a comprehensive world-class auto parts industry supply system, and the growth and expansion of the auto parts industry are advancing rapidly (Zhang et al., 2021). In July 2021, the city released two policy documents, "Opinions on Gradual Sub-regional Pilot Demonstration of Intelligent Networked Vehicle (Autonomous Driving) Application Operation Policy in Different Mixed Environments" and "Work Plan for Demonstrating the Application and Operation of Intelligent Networked Vehicles (Automated Driving) in Different Mixed Traffic Environments." These documents pave the way for piloting automated driving in mixed-traffic environments, building on the current development of the intelligent networked vehicle industry.

Furthermore, Guangzhou's "Intelligent Networked Vehicle (Telematics) Demonstration Application Scenario Catalogue" outlines the city's focus on travel optimization, demonstration operation, public services, and other directions, aiming to expedite the implementation of nine application scenarios. These include networked self-driving cars, BRT bus-road cooperative optimization, and high-speed intersection Telematics fast pass.

As part of the plan, by 2025, Guangzhou intends to complete multidimensional, comprehensive, and large-scale urban transportation trials across five stages. These trials will involve different proportions of mixed traffic environments, various degrees of vehicle-road coordination, and the introduction of numerous new travel services. Currently, the city has issued test notifications to numerous intelligent network-connected vehicles under ten test subjects, including Wenyuan Zhixing, Pony Zhixing, Baidu Apollo, and Guangzhou Automobile Group (Guangzhou People's Government, 2022). These notifications encompass more passenger test licenses for simulated commercial operation, along with more remote test licenses for conducting tests on different road sections, including the early pilot areas. Various types of testing work are being conducted on the first, second, and third-tier road sections opened in Guangzhou.

7.2. Shenzhen: City of Automobiles for the Whole Industry

Although Guangzhou and Foshan constitute two of the major automobile manufacturing bases in Guangdong Province, the auto industry in Shenzhen faced initial challenges. Nonetheless, it successfully transitioned to focus on new energy vehicles, leveraging its electronic information and electronic device industry advantages to carve a unique industrial path (Zheng et al., 2020). By adopting a market-driven approach and cultivating the market through demonstrations, Shenzhen's new energy vehicle industry gained rapid momentum since 2009 (Qu & Li, 2019).

Presently, Shenzhen proudly holds the distinction of being the first city in China to achieve full electrification of buses and cruising cabs. The city has also made significant strides in commercializing pure electric heavy vehicles, including sanitation trucks and tractors. As of the end of 2020, Shenzhen boasted a staggering 480,000 new energy vehicles, securing its position as the leader nationwide, constituting approximately 14% of the city's motor vehicle fleet.

Benefiting from its substantial expertise in electronics, information, communication, and artificial intelligence, Shenzhen is proactively accelerating its progress in the intelligent and networked automotive industry (Kobashi et al., 2020). Pingshan District, designated as the "future industry pilot zone" by the Shenzhen Municipal Party Committee and Municipal Government, has actively pursued intelligent networked vehicle industry developments. It has focused on platform construction, road testing, demonstration applications, industrial policy support, creating an open infrastructure environment, and pioneering vehicle networking initiatives.

Shenzhen's forward-looking efforts in Telematics have earned it a position as a pioneer demonstration zone in this domain.

Moreover, Shenzhen is utilizing its legislative power to explore legislation related to the commercialization of intelligent networked vehicles, aiming to provide institutional safeguards for early pilot implementations (Wu et al., 2021). In March of this year, the Shenzhen Municipal People's Congress issued the "Regulations on the Management of Intelligent Networked Vehicles in Shenzhen Special Economic Zone (Draft for Public Comments)." The proposed regulations aim to enable intelligent networked vehicles to drive on the roads of the Special Administrative Region upon obtaining registration certificates, number plates, and driving permits. The city government may designate administrative regions with comprehensive vehicle-road coordination infrastructure for road testing, demonstration applications, and commercialization pilots of intelligent networked vehicles throughout the whole area.

7.3. Zhaoqing: The Most Impulsive Boy

Zhaoqing, located on the west bank of the Pearl River, distinguishes itself from well-established automotive manufacturing powerhouses like Guangzhou and Shenzhen. Although considered a latecomer, the city has made impressive strides in the automotive industry through meticulous industry cluster planning, targeted industrial support policies, and a keen understanding of the automotive industry's development trajectory. It has seized the opportunity presented by the rapid growth of the new energy vehicle industry, leading to a swift transformation and upgrading of its industrial capabilities, driving progress and accumulating strength.

According to the Zhaoqing Statistical Yearbook (Zhaoqing People's Government, 2016), in 2015, there were 17 automotive manufacturing enterprises of significant scale in Zhaoqing, generating a total annual output value of approximately 7 billion yuan. While this figure was not remarkable within the city's manufacturing landscape, it was only a fraction of the output value seen in larger cities like Guangzhou and Foshan in the Pearl River Delta. However, by 2020, Zhaoqing's automotive industry had undergone significant growth, achieving a total industrial output value of 29.7 billion yuan.

With the involvement and influence of leading enterprises like Ningde Time and Xiaopeng Automobile, Zhaoqing has actively promoted the development of the local new energy automobile and auto parts industry (Zhaoqing Release, 2022). Initiatives to "build chain, extend chain, complement chain, and strengthen chain" have been launched, focusing on four core links: auto parts, vehicles, charging facilities, and the auto aftermarket. The auto parts chain consists of four major segments: new energy vehicle core parts, traditional auto core parts, auto electronics, and auto lightweight components, assessed based on local development level and future direction.

To further advance its position in the automotive industry, Zhaoqing established the "Zhaoqing City Intelligent Vehicle Industry Development Leading Group" in 2018 and issued the "Zhaoqing City Self-Driving Vehicle Road Test Management Implementation Rules (for Trial Implementation)." It became a pioneer in setting up the first domestic intelligent vehicle industry ecosystem, termed "three networks and one vehicle." This ecosystem encompasses the energy network, transportation network, vehicle network, and intelligent networked vehicles. To support this vision, a leading group for constructing the industrial ecology of "three networks and one vehicle," led by city leaders, has been established.

8. Conclusions and Recommendations

Through literature analysis using *CiteSpace* and *VOSviewer*, this paper confirms that there is a sustainable development trend in NEV in China, enhancing ITS in smart cities. Then, this paper introduces the application of IoT in China's NEVs and describes the current development of NEVs in China as well as charging infrastructure. In addition, this paper also describes the development of new energy vehicles in three cities, Guangzhou, Shenzhen, and Zhaoqing, using Guangdong Province as an example. Analysis of policy changes indicates that since the introduction of NEVs, the Chinese government has been continuously promoting the sustainable development of NEVs through measures like adopting laws and regulations, guidance and subsidies, etc. as well as facilitating technological innovation. From January 1, 2023, the state stopped subsidizing new energy vehicles, but some local governments still take the way to continue subsidizing them. China's new energy vehicles are changing from policy-driven to market-driven, and there is still a long way to go for future development.

In the future, the new energy vehicle industry will be full of development opportunities in the next few years. The first half has not yet completely ended, and the second half has just begun. An industry consensus is that the development of new energy vehicles is divided into the first half and the second half, marked by whether the industry has entered a new phase of development, which has two important features: one is electrification and the other is intelligence. The new content of electrification coupled with intelligence constitutes the main feature of the second half of new energy vehicles, the background of which is that electric vehicles have achieved scale development. Intelligent technologies and products will reshape the competitive landscape of the industry and create new industrial value. From the perspective of the existing competitive landscape of the new energy vehicle industry, each technology line has entered a relatively stable state. The focus of competition of products and enterprises no longer depends entirely on the power system, but more on the second half of competition in the auto industry, which is the intelligence based on electrification. A new systemic project will be formed based on intelligent networked vehicles. The development of China's intelligent networked vehicles involves many fields such as vehicles, roads, cities, and networks, and will form a new industrial ecology based on this, which is a systematic project that brings changes far beyond the cars themselves.

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