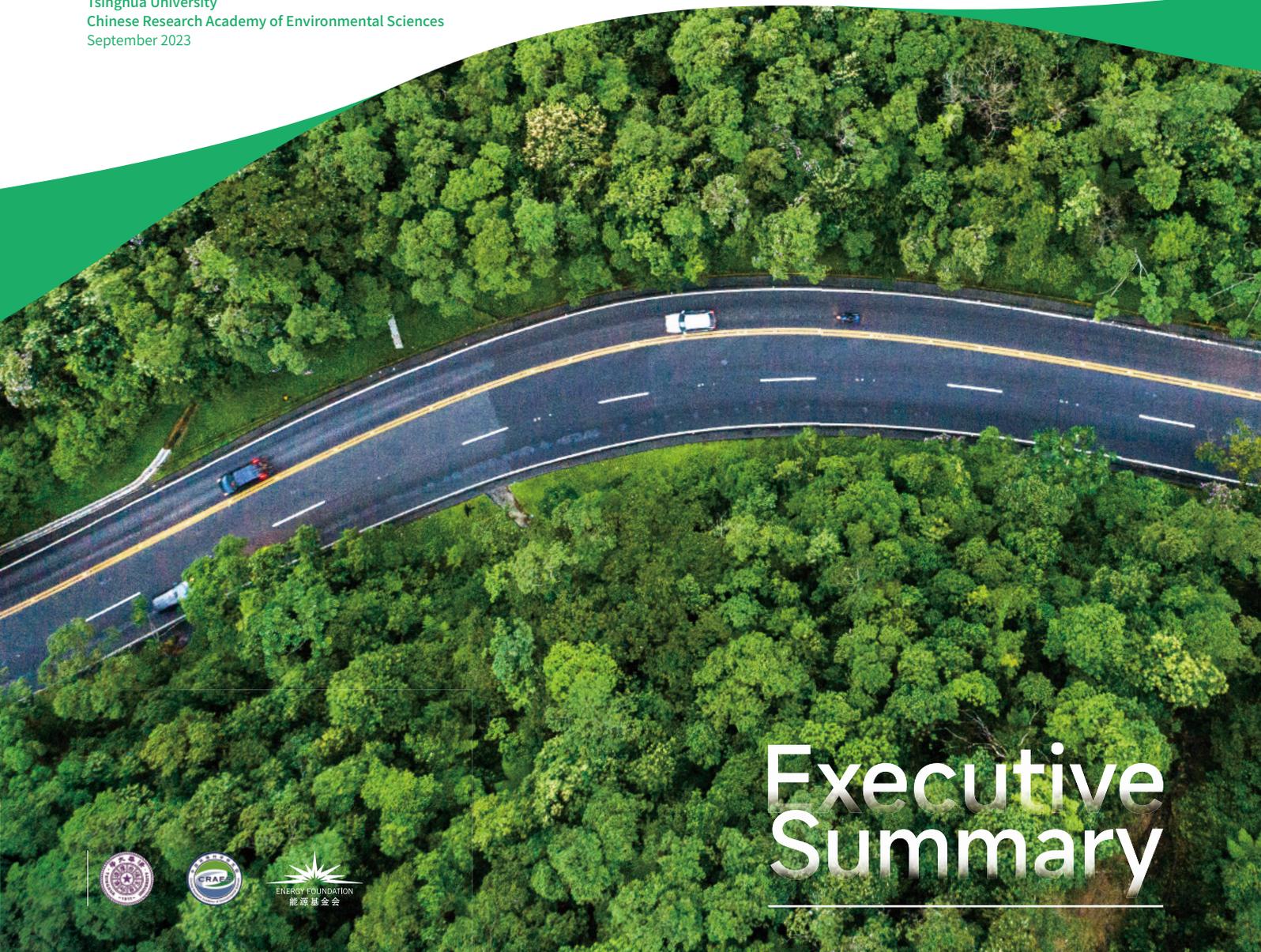


# A Retrospective and Prospective Study on 20 Years' Mobile Source Emissions Control in Megacities of China

Tsinghua University  
Chinese Research Academy of Environmental Sciences  
September 2023



## Executive Summary



## About authors:

---

### Principal investigators:

Ye Wu, Professor, School of Environment, Tsinghua University

Yan Ding, Chief Scientist, Vehicle Emission Control Center (VECC), Chinese Research Academy of Environmental Sciences

### Chairs of the international scientific committee:

Jiming Hao, Professor of Tsinghua University, Member of Chinese Academy of Engineering (CAE), and International Member of National Academy of Engineering (NAE) of the U.S.

Michael P. Walsh, Board Member Emeritus of the International Council on Clean Transportation (ICCT)

### Project team:

Ye Wu, Shaojun Zhang, Xiaomeng Wu, Yifan Wen, Liqiang He, Yunjie Wang, Min Liu, School of Environment, Tsinghua University

Yan Ding, Hang Yin, Junfang Wang, Dong Ma, VECC of the Chinese Research Academy of Environmental Sciences

Baoxian Liu, Yanyan Yang, Beijing Municipal Environmental Monitoring Center

Cheng Huang, Qingyao Hu, Junjie Tian, Shanghai Academy of Environmental Sciences

Min Yan, Pei Zeng, Shenzhen Research Academy of Environmental Sciences

Qinwen Tan, Danlin Song, Ye Deng, Zihang Zhou, Chengdu Research Academy of Environmental Sciences

Honglei Xu, Rui Wu, Renjie Wang, Daoyuan Yang, Transport Planning Research Institute, Ministry of Transport

Ying Liu, Weinan He, Beijing Traffic Institute

Hui He, Liuhanzi Yang, Tianlin Niu, Hongyang Cui, ICCT

### Members of the international scientific committee:

Jiming Hao, Professor of Tsinghua University, Member of CAE , and International Member of NAE (US)

Michael P. Walsh, Board Member Emeritus of the ICCT

Wei Zhou, Former Chief Engineer, Ministry of Transport, China

Kebin He, Professor of Tsinghua University, and Member of CAE

Hong He, Professor of Research Center for Eco-Environmental Sciences, Chinese Academy of Sciences, and Member of CAE

Anumita Roychowdhury, Executive Director, Research and Advocacy Centre for Science and Environment, India

Leonora Rojas-Bracho, Independent Researcher and Senior Consultant

Lennart Erlandsson, Independent Researcher and Senior Consultant

Jim Blubaugh, Director International Policy, Office of Transportation and Air Quality, U.S. Environmental Protection Agency

Supat Wangwongwatana, Senior advisor to Thailand Environment Institute and the Pollution Control Department



### **Acknowledgments:**

This research was jointly conducted by the School of Environment, Tsinghua University and the Vehicle Emission Control Center of the Chinese Research Academy of Environmental Sciences, with funding support from the Energy Foundation.

### **Disclaimer:**

Unless specifically stated, the views expressed in this report are solely those of the author and do not necessarily represent the views of the Energy Foundation. The Energy Foundation does not guarantee the accuracy of the information and data in this report, and is not responsible for any consequences resulting from the use of this report by any person.

Any reference to certain companies, products, or services does not imply endorsement or recommendation by the Energy Foundation, nor does it imply superiority over other similar companies, products, or services that are not mentioned.

Due to socioeconomic development and rapid urbanization, the automotive market in China has experienced exponential growth over the past three decades. This remarkable surge in motorization serves as a testament to China's thriving economy. Since 2009, China has held the position as the largest automotive market globally and in 2013, it became the first country to exceed annual sales of 20 million new vehicles. In terms of total vehicle population, China overtook the United States of America in 2021, solidifying its leading position. While rapid motorization contributes to industrial and social development by enhancing travel convenience, it also presents substantial challenges concerning air quality, public health, energy security, and climate change.

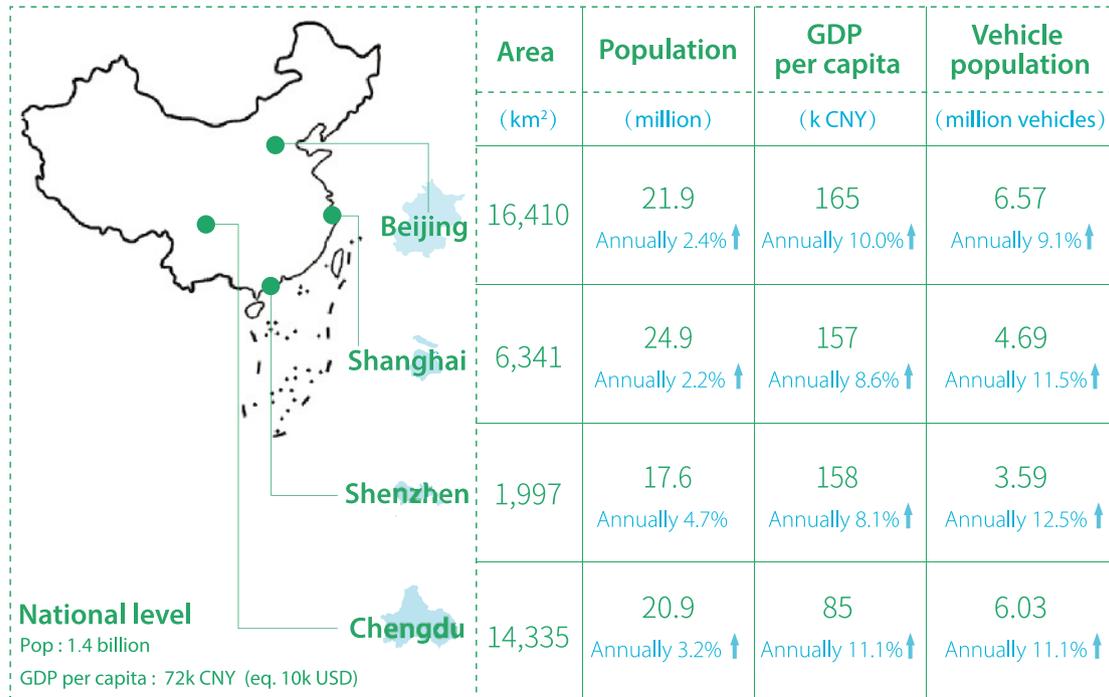
As early as the mid-1990s, China became aware of vehicle-related air pollution issues and started learning effective control measures from developed countries. In 2000, China implemented the China 1 emission standards, a milestone that marked the beginning of comprehensive control of vehicle emissions at the national level. During the past 20 years, China has formulated and implemented a series of control policies and measures to address this issue. These include continuous upgrades to vehicle emission standards, improvements in fuel quality, enhanced controls on in-use vehicle emissions, promotion of new energy vehicles (NEVs), and optimization of transport planning and management. As a result, the integrated “vehicle-fuel-traffic” control system has been developed and progressively enhanced (Fig.1). Currently, China has fully implemented the China 6/VI standards for vehicle emissions and fuel quality. Additionally, advanced technologies for monitoring real-world emissions have been piloted, and efforts to optimize transportation modes and energy structures have been initiated. Notably, China has emerged as a global leader in promoting NEVs. These two decades of concerted efforts have significantly reduced the gap between vehicle emission control in China and that in most developed countries.

**Fig.1. Integrated “vehicle-fuel-traffic” emission control system in China**



In China, megacities have played a crucial role in showcasing new measures for controlling vehicle emissions, resulting in progress on a national scale. Megacities, being hubs of vehicle concentration and frequent usage (Fig. 2), constantly strive to regulate vehicle emissions and enhance air quality.

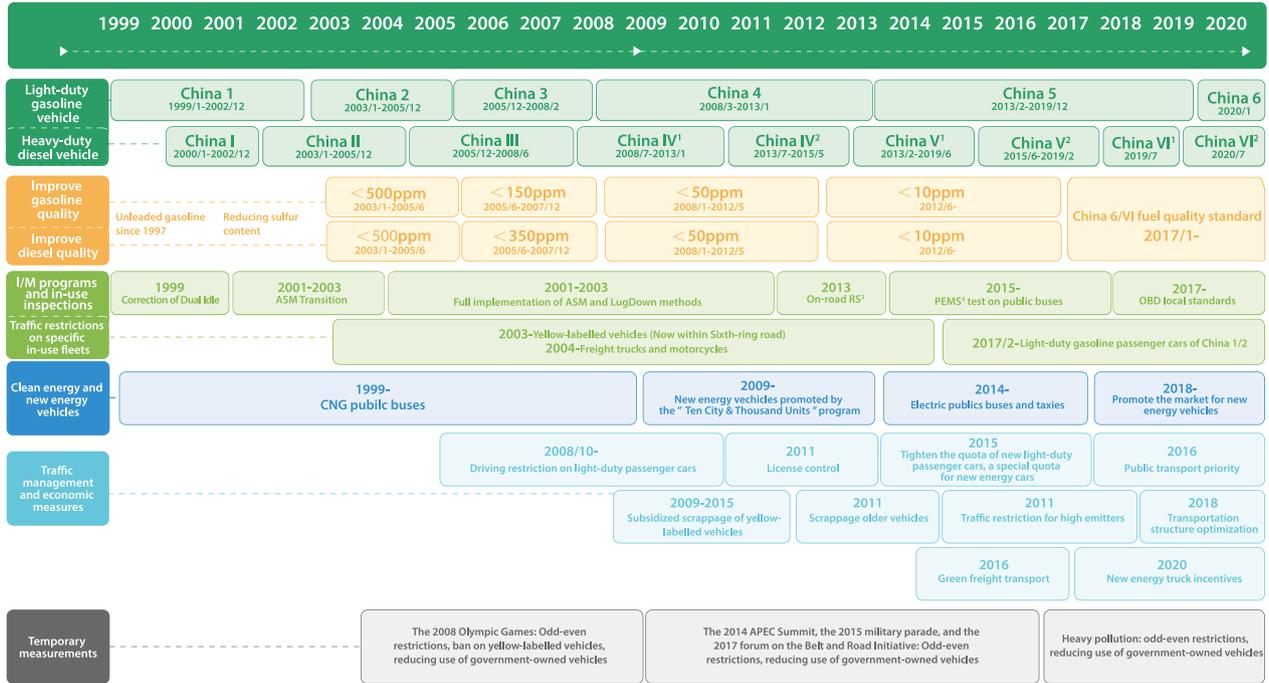
**Fig. 2. Economic and demographic conditions of Beijing, Shanghai, Shenzhen, and Chengdu in 2020**



The practical experiences gained from these megacities can serve as valuable support for implementing effective vehicle emission control policies at the national level. For example, over the past two decades, Beijing has pioneered the development of the integrated “vehicle-fuel-traffic” control system. This included the prohibition of leaded gasoline in 1997 and the implementation of the China 1 emission standard for light-duty gasoline vehicles (LDGVs) in January 1999. These measures were later adopted by the central government after one or two years (Fig. 4). In Shanghai, notable progress has been made in promoting public transport systems and diversifying transport energy. Shenzhen has achieved a significant milestone by being the first city in the world to fully electrify its public bus and taxi fleets, leveraging its well-developed local NEV industry. Lastly, Chengdu has developed a smart, data-driven system for managing vehicle emissions by utilizing extensive traffic data collected from intelligent transport systems. All these cities have implemented various control measures and practices tailored to their unique characteristics (Fig. 3). Despite significant increases in the number of vehicles, they have effectively managed to decouple urban transportation development and the trend of on-road emissions (Fig. 5, for the Beijing case). These studies have not only accelerated the improvement of air quality in megacities but also provided valuable insights for other cities to pursue green and low-carbon development paths for their transportation systems.

**Fig. 3. Featured municipal-level control policies in four representative megacities in China**

**Beijing: A pioneer city for vehicle-fuel-traffic integrated control**

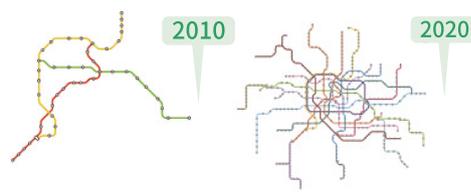
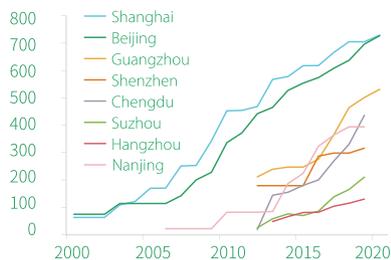


<sup>1</sup> Only implemented for public fleets; <sup>2</sup> for freight trucks and long-distance coaches; <sup>3</sup> remote sensing test; <sup>4</sup> portable emission measurement system

**Shanghai : Promoting public transport systems and diversifying transport energy**

- Subway development
- Application of biodiesel

Operating mileage of rail transit (km)



## Shenzhen : Promoting new energy vehicles and establishing comprehensive industrial layout

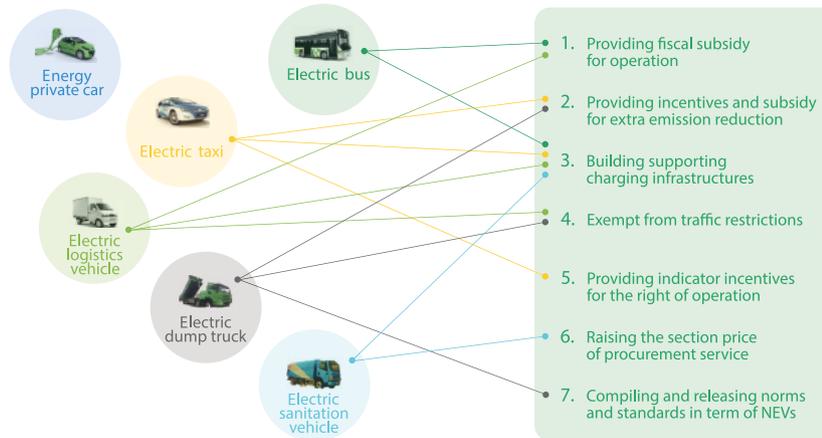
### Common measures

1. Policy support
2. Fiscal purchase subsidy
3. Promoting the construction of public charging infrastructures



1 Bus charging station 2 Car charging station

### Special measures



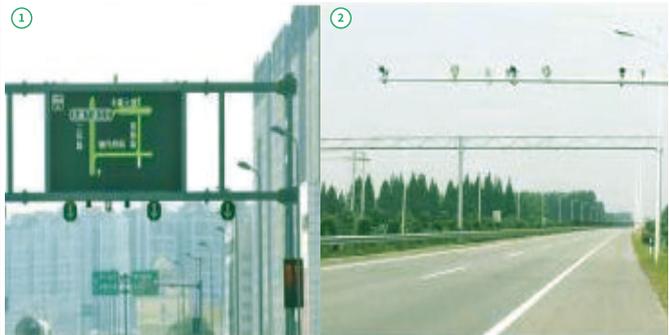
## Chengdu: Big-data intelligent transportation system promotes precise emission control

### Intelligent vehicle emissions mapping and management system

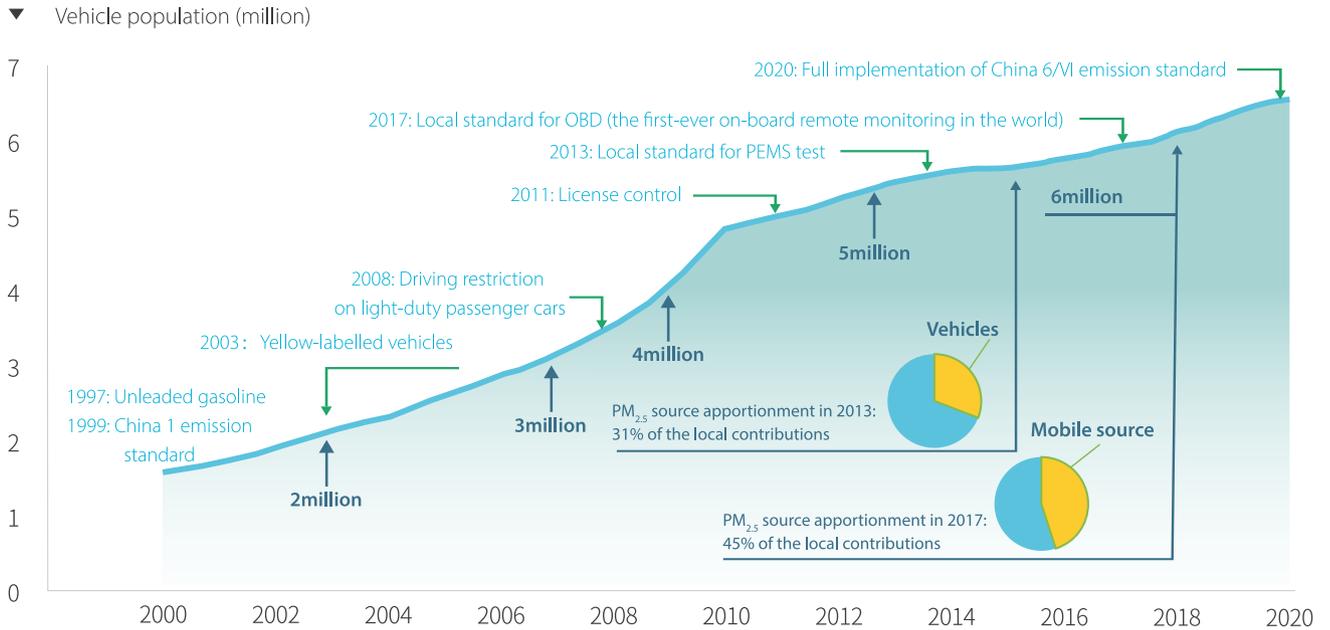
### ITS facilities



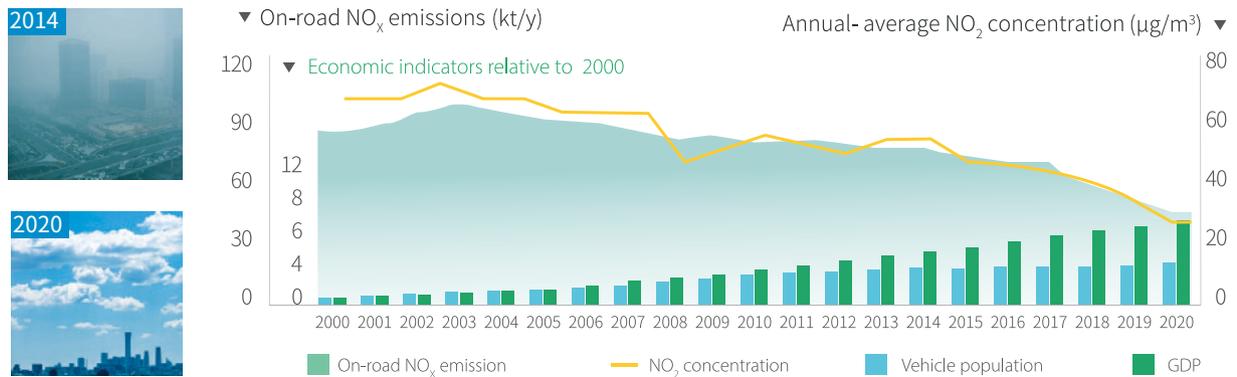
Hourly, link-based



**Fig. 4. Growth trend in vehicle population and key moments regarding vehicle emission control in Beijing during 2000-2020**



**Fig. 5. Decoupling on-road emissions resulting from rapid growth of vehicle ownership in Beijing during 2000-2020**



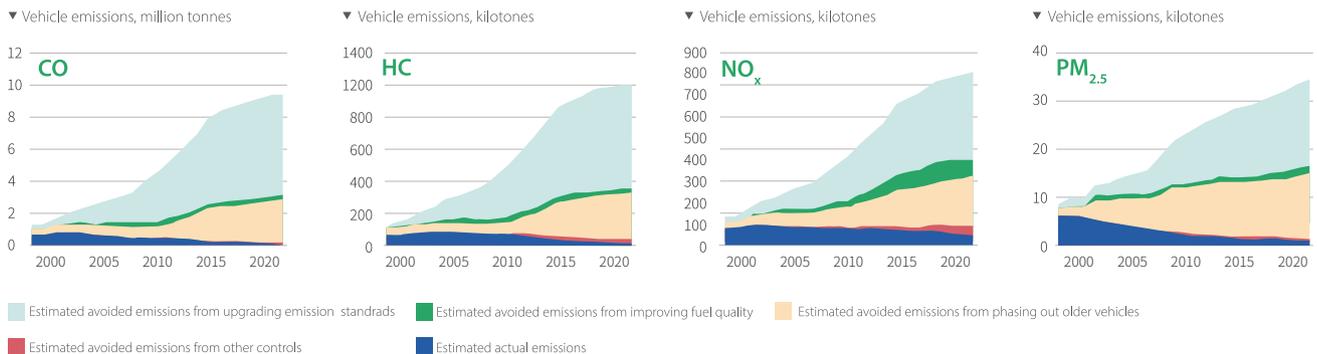
The significant observations from vehicle emission management in Beijing, Shanghai, Shenzhen, and Chengdu along with the progress made at the national level over the past two decades are summarized below.

# 1 Simultaneous enhancement of vehicle emissions and fuel quality standards

Enhancements in emission standards have played a central role in reducing on-road emissions in China over the last 20 years. Notably, Beijing has continuously tightened its emission standards for new vehicles. In January 1999, Beijing became the first Chinese city to implement the China 1 emission standards (equivalent to Euro 1) for LDGVs and since then it has consistently implemented more stringent vehicle emission standards compared to other cities in China. This has established Beijing as the national leader in vehicle emission control. In 2020, Beijing adopted the China 6/VI emission standards, which are among the most rigorous regulations worldwide, and these standards were subsequently adopted nationwide. The continuous enhancement of emission standards not only promotes the advancement of the automotive industry but also safeguards the environment.

Moreover, Beijing’s success highlights the importance of integrating vehicle emissions and fuel quality standards to maximize the emission reduction benefits of existing vehicle emission standards. In the late 1990s, Beijing began improving its fuel quality standards by prohibiting leaded gasoline (1997) and high sulfur content fuels (2012). When nationwide implementation of emission standards faced delays due to the lack of high-quality fuels (e.g., low sulfur content diesel fuels), Beijing took the lead in implementing fuel standards in China’s 2/II to 5/V stages, ensuring synchronized implementation with emission standards. The timely upgrading of fuel quality standards in Beijing served as a model for the harmonized improvement of vehicle emissions and fuel quality in China. Specifically, Beijing’s experience facilitated the nationwide implementation of China 5/V emission and fuel quality standards while unifying the on-road and non-road diesel fuel standards under China 6/VI. These synchronous enhancements in emission and fuel quality standards have effectively reduced vehicle emissions in Beijing. These improvements are responsible for 74%, 73%, 66%, and 55% of the total vehicle emission reductions in carbon monoxide (CO), hydrocarbon (HC), nitrogen oxides (NO<sub>x</sub>), and fine particulate matter (PM<sub>2.5</sub>) emissions from 2000 to 2020 (Fig. 6).

**Fig. 6. Assessment of vehicle emission reduction in Beijing during 2000-2020**



## 2 Integration of multiple advanced technologies for the emission monitoring of in-use vehicles

---

Supervising in-use vehicles has always been a crucial yet challenging aspect of vehicle emission control. To strengthen compliance with the real-world emission standards for existing vehicle fleets, China has implemented several new regulations and standards that combine multiple advanced technologies with in-use inspection and compliance programs.

Taking Beijing as a representative example, a comprehensive inspection system that integrates multiple monitoring techniques for in-use vehicles has been developed, and a regular supervision mechanism has been established after 20 years of practice. This system has strengthened the inspection and maintenance (I/M) program which plays a pivotal role in controlling emissions from in-use vehicles. Over the past two decades, Beijing has consistently adopted advanced inspection technologies to monitor emissions from in-use vehicles.

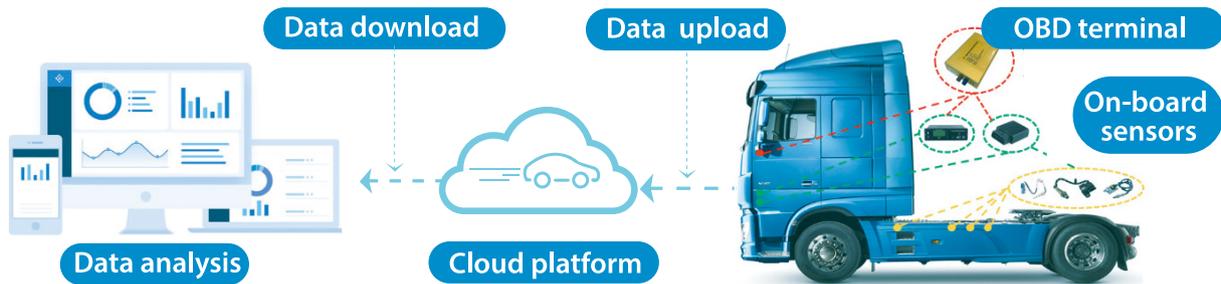
In 1999, Beijing revised the two-speed idle test method and the standard limits for new vehicles manufactured after the implementation of the China 1 standards. The more stringent acceleration simulation mode (ASM) method was fully implemented in 2003, with subsequent updates that further tightened the emission limits. For in-use diesel vehicles, Beijing introduced a lug-down test in 2003 further tightening the smoke emission limits. These advanced methods along with stringent emission limits, have significantly improved the ability to accurately identify high emitters.

In recent years, Beijing has embraced more real-world methods to improve its supervision capabilities and facilitate the development of comprehensive supervision platforms. Various advanced on-road monitoring technologies, including roadside remote sensing, portable emission measurement systems (PEMS), and remote on-board diagnostics (OBD), have been applied in Beijing.

Among the pollution challenges, the excessive real-world NO<sub>x</sub> emissions from heavy-duty diesel vehicles (HDDVs) is the most prominent issue for policymakers. Beijing became the world's first city to implement remote OBD monitoring to enhance the compliance of in-use HDDVs. Local standards and regulations were introduced requiring original equipment manufacturers to participate in the installation of OBD devices for new and in-use HDDVs. These local experiences resulted in the assimilation of remote OBD monitoring protocols in the China VI emissions limits. Currently, an online platform with over 100,000 in-use HDDVs has been preliminarily established (Fig. 7).

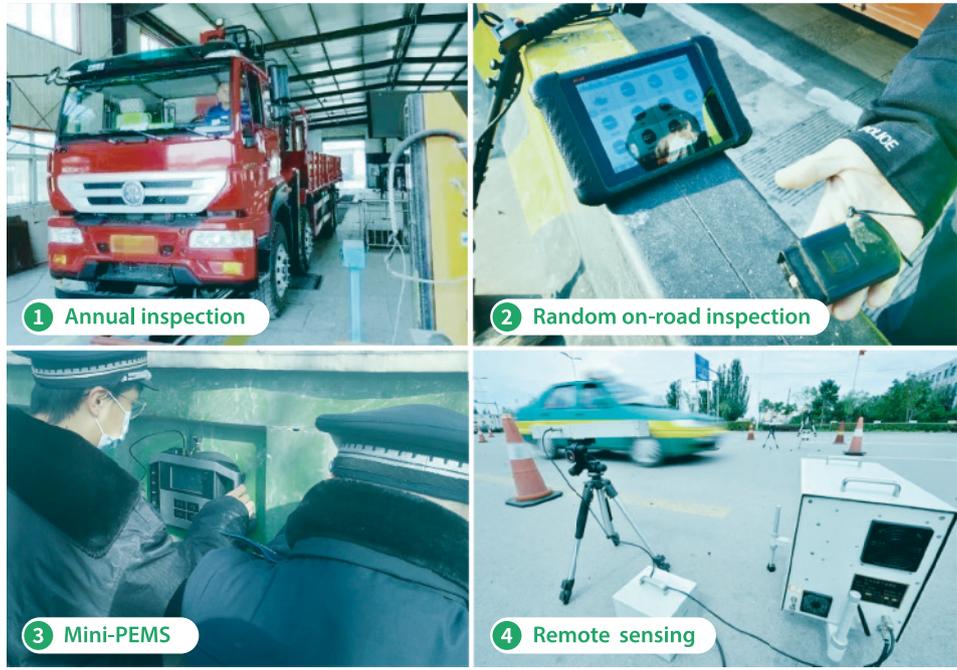
The powerful and efficient remote OBD monitoring has resulted in significant reduction in NO<sub>x</sub> emissions from HDDVs in Beijing. The average NO<sub>x</sub> emission factor for Beijing V HDDVs equipped with OBD monitoring is 50-70% lower than that of regular China V HDDVs without OBD monitoring, leading to effective mitigation of PM<sub>2.5</sub> and nitrogen dioxide (NO<sub>2</sub>) pollution. Notably, in Beijing, the estimated NO<sub>x</sub> emissions from diesel trucks in 2020 decreased by 43%, compared to 2017, surpassing California's reduction rate over the same three year period (~37%). Consequently, the annual average ambient NO<sub>2</sub> concentration in Beijing decreased by 37% during these three years, meeting the national ambient air quality standard for the first time in 2019.

Fig. 7. Beijing's remote on-board diagnostics (OBD) monitoring platform for heavy-duty diesel vehicles (HDDVs)



To summarize the experience gained from in-use vehicle supervision, China has established inspection and maintenance (I/M) programs, including annual emission inspection, random emission inspection, PEMS, and remote sensing (Fig. 8). The installation of on-board monitoring hardware is mandatory for the China VI-a standards for HDDVs, and data submission is required to adhere to the China VI-b standards, emphasizing the future importance of OBD monitoring.

**Fig. 8. Annual inspection and random on-road emission inspection of in-use vehicles**



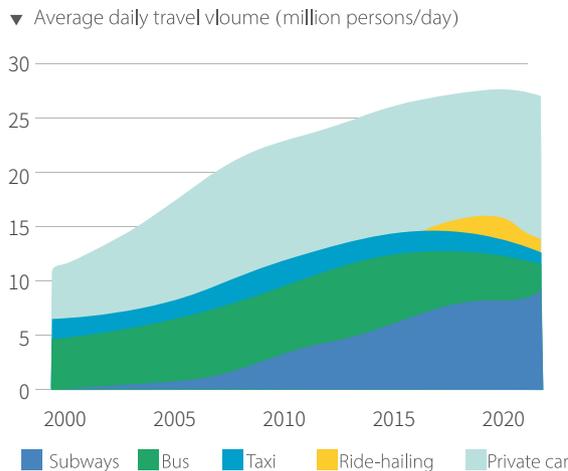
### 3 Implementation of “Prioritizing Public Transport” strategy and optimization of freight transportation structure

Reshaping public transport systems and encouraging sustainable green travel modes are fundamental measures for cities to develop green and low-carbon transport systems amidst urbanization. Cities, such as Shanghai and Beijing attach great importance to optimizing public transportation systems and non-motorized transport modes to cope with the increasing pressure of transportation demand while transitioning to efficient, green, and low-carbon transportation.

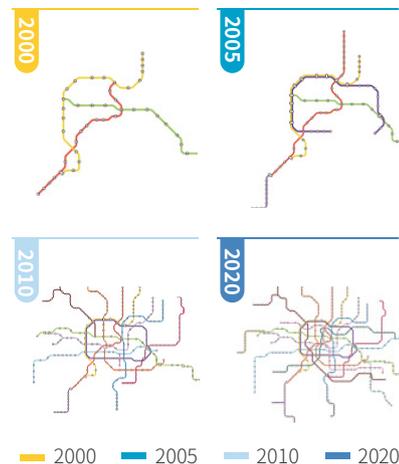
Shanghai was the first city in China to adopt the “Prioritizing Public Transport” strategy as a key component of urban development. In conjunction with urban and traffic planning, Shanghai has issued a series of policies to develop subways, optimize bus routes, and encourage public transport and non-motorized transport modes. Alongside license quota restrictions, the urban transport structure in Shanghai has undergone significant optimization, effectively alleviating traffic-related environmental problems (Fig. 9). In 2020, the proportion of public transport in Shanghai increased to 47% of trips, and the length of Shanghai’s subway lines exceeded 700 km, representing a tenfold increase compared to 2000. The total length of bus-only lanes reached 500 km, and the central area achieved full coverage of bus stops within a 300 m radius. Notably, in 2020, the vehicle ownership density in Shanghai was capped at approximately 180 vehicles per 1000 people, the lowest among other domestic megacities with similar gross domestic product (GDP) per capita. As a result, vehicular NO<sub>x</sub> and volatile organic compound (VOC) emissions in the region have continuously decreased. The NO<sub>2</sub> concentration in the urban area decreased by 18% from 2015 to 2020, with significant reductions observed in high concentration areas (Fig. 10). Over the past 20 years, Shanghai has successfully pioneered a green and low-carbon transportation development path that combines a public transportation priority strategy with comprehensive control of traditional vehicle emissions.

**Fig. 9. Changes in travel mode and development of subways in Shanghai**

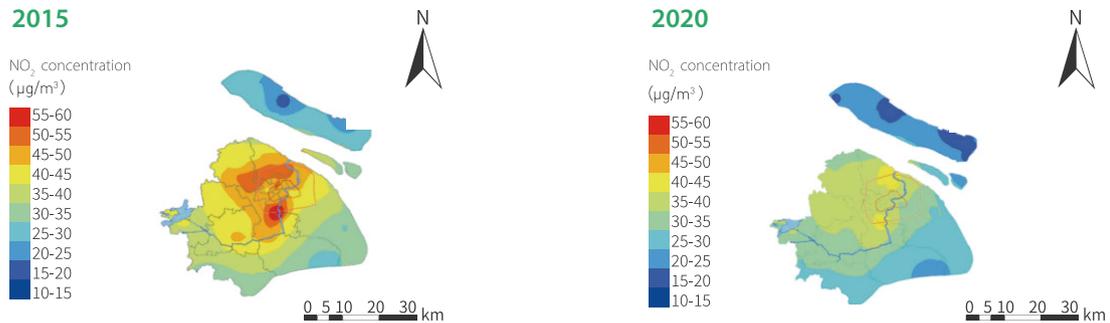
#### a. Travel volume and travel mode



#### b. Development of subways



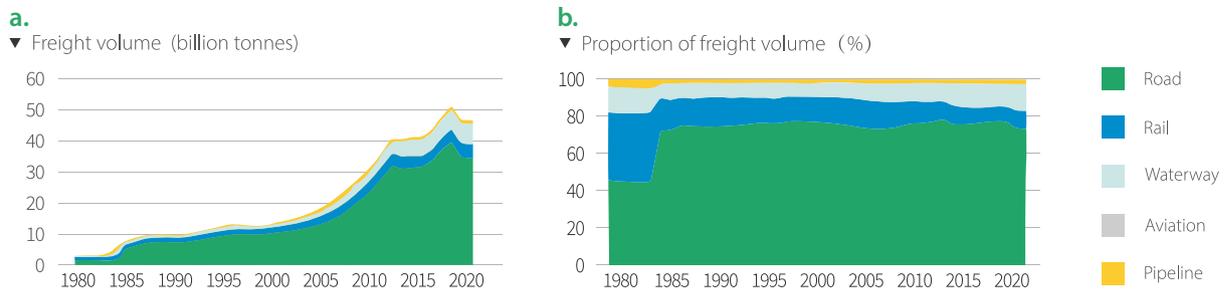
**Fig.10. Spatial distribution of ambient NO<sub>2</sub> concentrations in Shanghai in 2015 and 2020**



Over the past two decades, China has witnessed a rapid increase in freight transportation volume, currently ranking first globally. On-road trucks have dominated the freight transportation volume, while the proportion of railway transportation has continued to decrease. Generally, waterways and railways exhibit significantly lower energy consumption and pollutant emissions per unit of freight turnover compared to on-road trucks. Therefore, increasing the proportion of railway and waterway systems through modal shift can effectively reduce air pollutants and CO<sub>2</sub> emissions. Optimizing the transportation structure is of great significance in achieving vehicle emission mitigation, especially for heavy-duty trucks, and supply-side structural reforms.

The Three-Year Action Plan for Winning the Blue-Sky Defense War and the Three-Year Action Plan for Promoting Transportation Structure Adjustment have emphasized the crucial role of adjusting the transportation structure in controlling diesel truck pollution. To promote the “road to rail” and “road to water” transitions for bulk cargo transportation, the Chinese government has implemented economic measures and support policies for infrastructure construction. Since the implementation of these action plans, the predominant role of road transportation has started to shift. From 2017 to 2020, the share of railway cargo transportation in China experienced a rebound, with an average annual growth rate of 7%, while the share of road cargo transportation decreased from 78% in 2017 to 74% in 2020. Notably, the transportation structure for bulk goods in coastal ports in the Bohai Rim and Yangtze River Delta regions has undergone significant optimization. However, compared to the historical proportion of railway freight (over 30% in 1980), the adjustment of the transportation structure is still in its early stages (Fig. 11).

**Fig. 11. Trends in freight volume and modal proportion in China during 1980–2020**



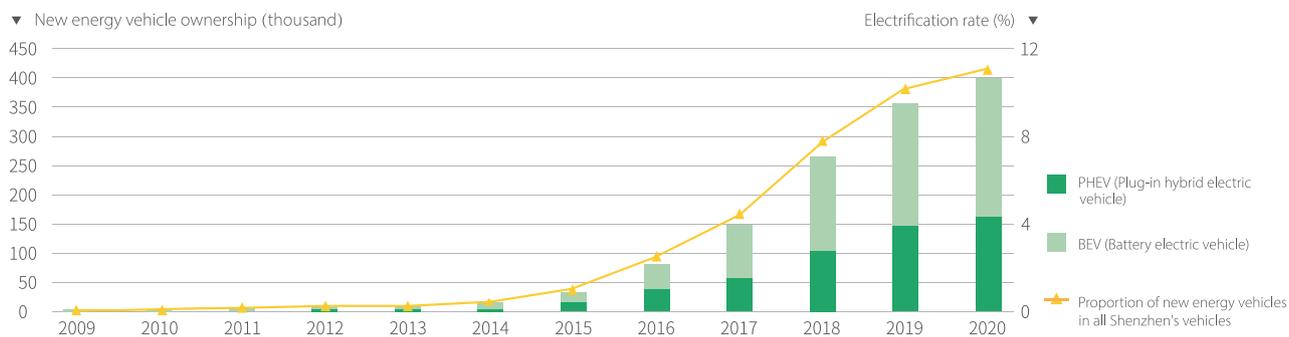
# 4 Comprehensive development of new energy vehicles (NEVs) and promotion of zero-emission vehicles

The promotion of NEVs offers significant benefits as they have the ability to synergistically reduce pollutants and carbon emissions. To align with global sustainability goals and mitigate climate change, it is critical for China to develop a clean and efficient modern energy system and achieve a green and low-carbon industrial transformation. This is also a key measure for China to meet its long-term objective of clean air and carbon neutrality. China pioneered the “Ten Cities, Thousand New Energy Vehicles”) demonstration project in 2009, which involved 1,000 NEVs in 10 cities. Since then, China has launched a series of measures to promote NEVs and currently holds the title of the world’s largest producer and seller of NEVs. These measures include purchase subsidies, tax exemptions, infrastructure construction, and the promotion of dual-credits for corporate average fuel consumption-sales of new energy vehicles (CAFC-NEV). By the end of 2020, the NEV stock in China reached 4.92 million, accounting for over 40% of the global NEV total and exhibiting sustained rapid growth.

Shenzhen is one of the pioneer cities in China for significantly promoting the use of NEVs and has been awarded the title of the “Capital of Electric Vehicles in the World” for six consecutive years. Shenzhen has successfully promoted approximately 400,000 NEVs, which accounts for 11% of its total vehicle stock. Not only does Shenzhen have the highest electrification rate among all Chinese megacities, Shenzhen is also the first city in the world to fully electrify its bus and taxi fleets, and it had the highest number of electric trucks globally from 2015 to 2020.

The rapid development of electric vehicles in Shenzhen can be attributed to the comprehensive construction of a supportive system and the establishment of a sound NEV industry layout. Over the past 10 years, the city has issued more than 30 standards and administrative rules directly related to NEVs. Additionally, a comprehensive support system, including development planning, standard specifications, financial subsidies, and infrastructure construction, has been established. For example, Shenzhen has introduced diverse subsidies and incentive measures that cover different aspects of NEVs, such as purchase, usage, infrastructure, and battery recycling. Furthermore, fiscal incentives have played a significant role in promoting NEV development in the city. Notably, Shenzhen places great importance on the local landscape and ecosystem of the NEV industry. At present, Shenzhen has more than 2,000 NEV-related enterprises making it one of the cities with the highest density of NEV enterprises in the world.

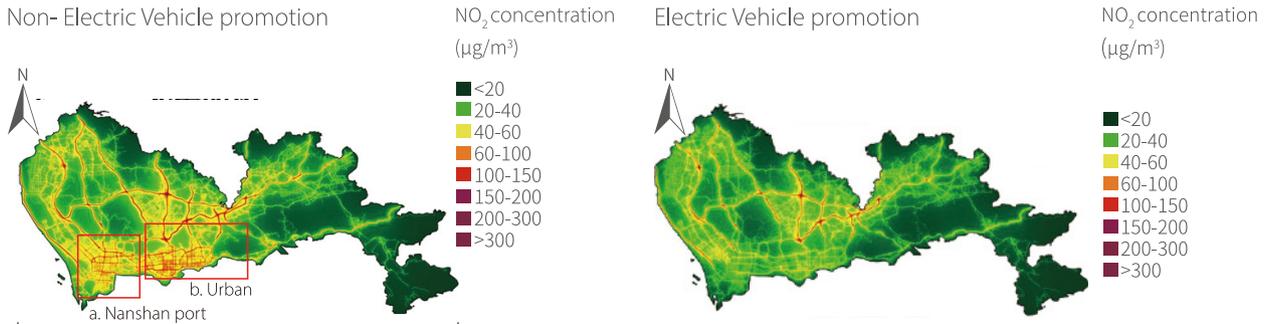
**Fig. 12. Growth in the total number of new energy vehicles (NEVs) in Shenzhen during 2009–2020**



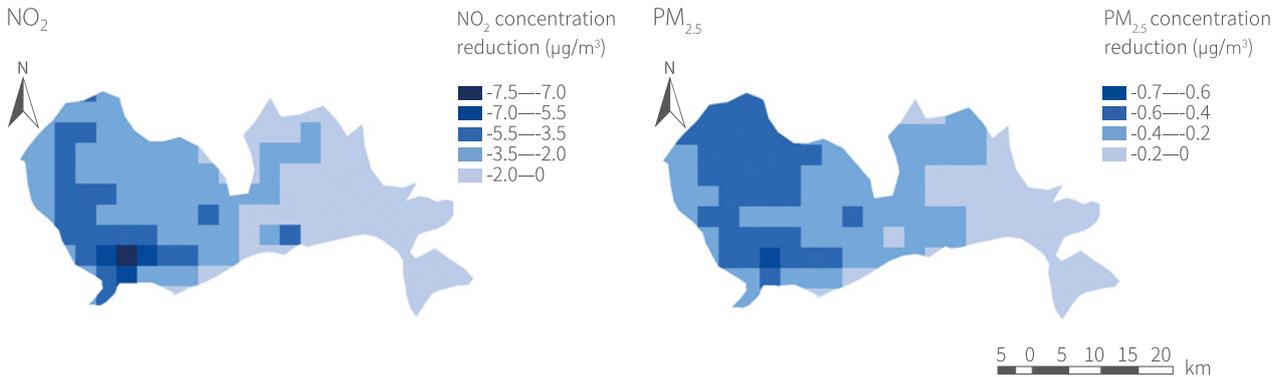
The rapid development of NEVs in Shenzhen has become a crucial element in achieving a local clean-air action plan known as “Shenzhen Blue”. Since 2014, ambient  $\text{NO}_2$  concentrations in Shenzhen have significantly improved, with 35% of the improvement attributed to fleet electrification (Fig. 13a). Further large-scale promotion of NEVs will continue to bring substantial improvements in air quality, such as coordinated control of  $\text{PM}_{2.5}$  and ozone ( $\text{O}_3$ ) pollution (Fig. 13b), along with associated health benefits. Moreover, NEVs will make significant contributions to reducing greenhouse gas emissions from on-road traffic throughout their life cycle.

**Fig. 13. Air quality improvements in Shenzhen resulting from fleet electrification**

**a. Current benefits(2019)**



**b. Future benefits(2030)**





To address food safety concerns arising from the reuse of waste cooking oil (“gutter oil”), Shanghai has established a closed-loop management system for the entire waste cooking oil treatment industry. The system covers various aspects such as the collection, transportation, storage, disposal, and application of gutter oil (Fig. 15).

**Fig. 15. Illustration of the closed-loop governance model applied in Shanghai for the complete industrial chain of “gutter oil” to biodiesel**

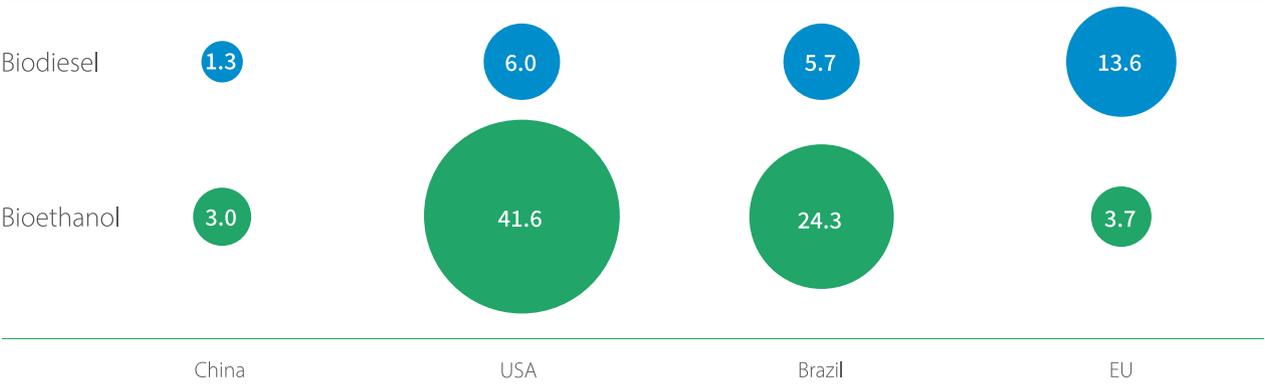


Additionally, Shanghai has implemented the widespread use of B5 (a blend of 5% biodiesel and 95% diesel) and B10 biodiesel in buses and heavy-duty vehicles (HDVs). The amount of waste cooking oil collected in Shanghai has increased to over 200 tonnes per day, which can be converted into 50,000 tonnes of B100 biodiesel annually, replacing approximately 1% of diesel consumption in the transportation sector. These measures not only contribute to emission reduction and energy conservation but also provide valuable insights for the diversification of transportation energy in cities.

It is important to note that the scale of biofuel promotion in China lags behind that of countries like Brazil and the United States of America (USA). In 2020, bioethanol production reached 41.6 million tonnes in the USA and 24.3 million tonnes in Brazil, while biodiesel production in the European Union (EU) amounted to 13.6 million tonnes (Fig. 16). Therefore, considering China’s commitment to reaching its CO<sub>2</sub> emission peak by 2030 and achieve carbon neutrality by 2060, more efforts are needed to promote research and development of biofuels in China.

**Fig. 16. Comparison of biofuel production in China, Brazil, the United States of America (USA) and the European Union (EU)**

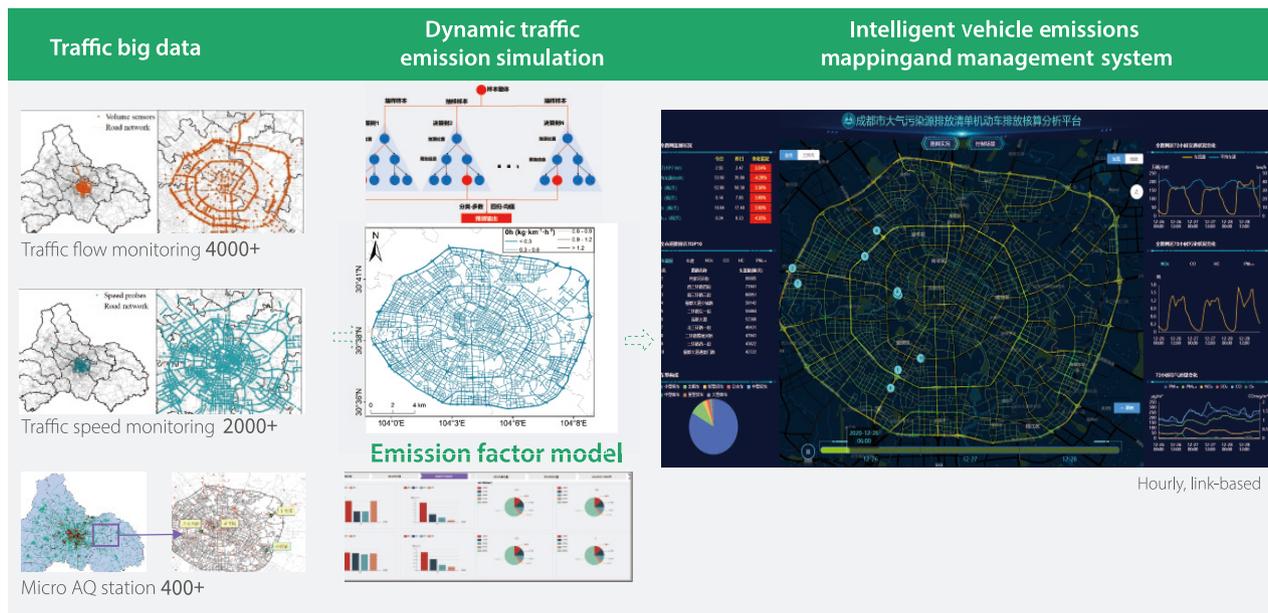
▼ Production in 2020 (million tonnes)



# 6 Big data intelligent transportation system to promote smart management of vehicle emissions

Intelligent transportation technology and the utilization of traffic big data can be effective strategies for intelligent traffic emission control. Rather than implementing license control measures to cap the growth of the total vehicle population, Chengdu, like other megacities, focusses on addressing traffic and environmental issues through data-driven intelligent technologies. In recent years, Chengdu has made significant efforts to develop and utilize Intelligent Transportation Systems (ITS). The city has established a monitoring network with a high density of traffic detectors (approximately 4,000 detectors within the urban area as of 2020) that transmit real-time traffic volume and fleet composition data. Integrated with a machine learning (ML) based traffic flow simulation method, Chengdu has developed a dynamic vehicle emission mapping and management system (Fig. 17). The latest version (V4.0, released in 2021) of this comprehensive decision-making system enables fast, accurate and high-resolution vehicle emission simulations for the entire city. For example, the system can effectively demonstrate link-level traffic flow and vehicle emissions continuously for 72 hours. The platform also allows for simulating the benefits of vehicle emission control in both short- and long-term scenarios, thereby improving the timeliness, accuracy, and intelligence of traffic emission supervision. The platform has been successfully utilized for dynamically tracking traffic and emission changes during the COVID-19 pandemic and evaluating the low-emission zone (LEZ) policy to ensure optimal traffic control during major events, such as the Chengdu World Police and Fire Games. It has provided significant technical support for fast and precise decision-making regarding vehicle emission control in Chengdu (Fig. 18).

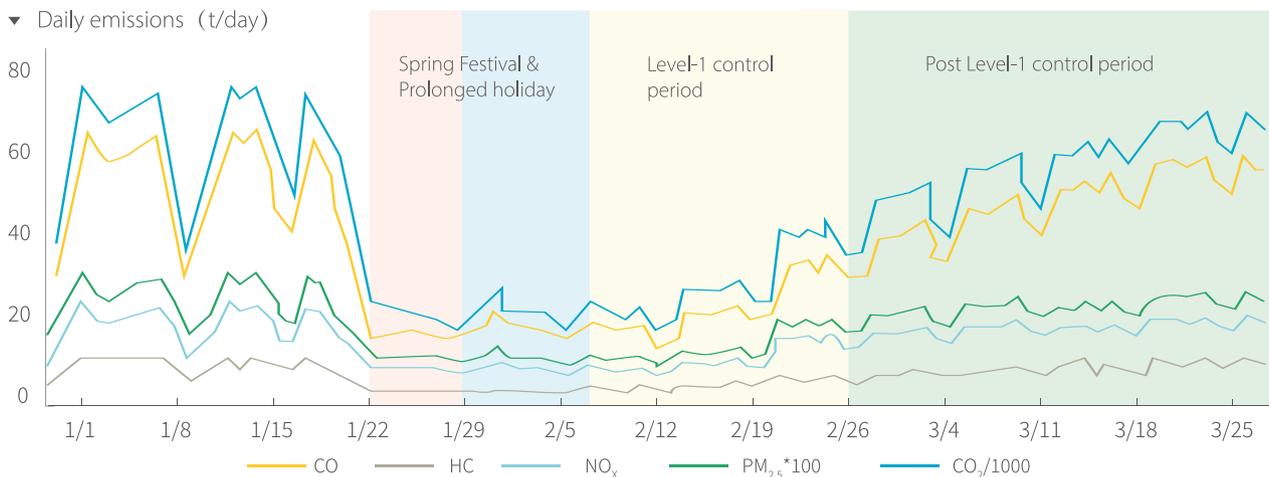
**Fig. 17. On-road vehicle emissions mapping and management system of Chengdu based on Intelligent Transportation Systems (ITS) big data**



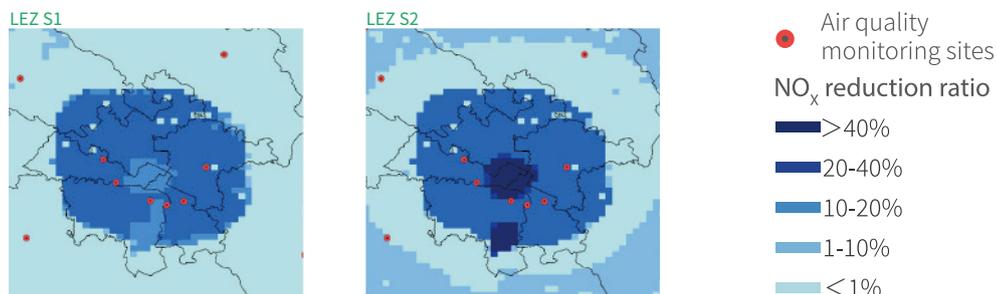
Assessments of the feasibility and expected effects of the LEZ policy indicate that its implementation in Chengdu can significantly reduce traffic intensity and vehicle emissions, leading to improved air quality in the city (Fig. 18b). In addition, the LEZ policy can be integrated with NEV promotion and transportation structure adjustments enhancing its role as a “green and low-carbon demonstration zone” that mitigates air pollution and CO<sub>2</sub> emissions. This conceptual leap could become an important strategy for developing green and low-carbon transportation systems in large cities. However, it is crucial to note that the successful implementation of the LEZ policy requires adequate legal support and supportive infrastructure. Therefore, careful consideration of all stakeholders and their concerns is necessary before implementation. Moreover, dynamic tracking and thorough evaluation is necessary before and during the policy’s implementation. Importantly, the experience gained from applying big data ITS analytics can assist cities in achieving smart vehicle emission management and provide innovative solutions to other cities facing similar challenges due to rapid motorization.

**Fig. 18. Implications of the on-road vehicle emissions mapping and management system applied in Chengdu.**

**a. Dynamic tracking of vehicle emission changes during the COVID-19 pandemic**



**b. Assessment of emission reduction resulting from the implementation of low-emission zone (LEZ) policies**



# Outlook

---

Although China has made tremendous progress and achievements in vehicle emission control, there is still a long way to go. With the projected vehicle stock reaching 400-500 million by 2030 the construction of a sustainable, clean, and low-carbon transportation system becomes a crucial task in the future development of China's transportation sector.

## **01 Deep emission abatement is critical for improving air quality and addressing climate change synergistically**

Deep emission abatement for mobile sources is a major focus for reducing  $PM_{2.5}$  and  $O_3$  concentrations in China's megacities. Implementing scientifically based and precise vehicle emission control measures is a critical task to improve the air quality in China by 2035, aligning with the country's goal of building a "beautiful China." Achieving the 2060 carbon neutrality target requires improvements in vehicle energy efficiency, transportation structure optimization, and clean energy transition, leading to significant pollutant and emission reductions and air quality improvement.

## **02 Enhancing the leading role of standards and technologies and increasing control of vehicle emissions from internal combustion engines (ICEs)**

Continuously tightening emission standards, particularly for  $NO_x$  reduction by introducing ultra-low  $NO_x$  limits for HDVs and promoting the development of more efficient engines and after-treatment technologies with ultra-low emissions, are crucial. Future emission standards should focus on technology-neutral and fuel-neutral emissions, with a particular emphasis on regulating and inspecting real-world vehicle emissions. Consideration can also be given to regulating additional pollutants such as ammonia ( $NH_3$ ) and formaldehyde (HCHO) alongside tightening the emission limits of regulated pollutants like  $NO_x$  and total hydrocarbon/non-methane hydrocarbon (THC/NMHC), and exploring the synergistic control of greenhouse gas emissions.

## **03 Clean and low-carbon energy transition for the transportation sector can heavily promote the green development of the automotive industry**

Clean and low-carbon energy transition in the transportation sector is a fundamental measure for achieving multi-pollutant control and synergistic  $CO_2$  reduction. For the LDV sector, promoting the large-scale adoption of electric vehicles to take full advantage of their life-cycle carbon reduction and operational cost benefits is crucial. For commercial vehicles (CVs), diverse technological demands of NEVs should be considered based on comprehensive CV types and operational behaviors. Comprehensive studies on the environmental benefits and costs for different operational segments are needed to establish clear and appropriate CV development plans, according to different NEV technology advantages. Regulating proper action plans and timescales for electric vehicle or hydrogen fuel-cell vehicle technologies and infrastructure development is important based on

---

the cost and emission reduction potential of these technologies. Integrating data for the energy, industry, and supply chains, such as a full life-cycle emission evaluation platform for city-level or regional-level NEVs and clean energy, can effectively support the long-term development and promotion of NEVs and low-carbon biofuels. The deep integration of energy and transportation systems can powerfully promote the development of intelligent NEV infrastructure systems and intelligent energy systems, such as battery swap networks or smart charging networks, significantly improving the convenience and emission reduction capabilities of NEVs.

#### **04 Strengthening infrastructure development and improving service performance to facilitate green travel systems and optimize freight structure**

Policymakers should prioritize public and non-motorized transport modes to promote urban green travel. Transitioning to low energy-consumption, low-emission, and high-efficiency transportation modes is required. The Internet of Things (IoT) and big data technology can contribute significantly to intelligent public transport systems that integrate traveler, vehicle, route, station, and cloud data to achieve better green travel systems. Another target should be the optimization of freight structure by speeding up infrastructure construction, improving service levels, innovating service models, enhancing multimodal transportation capabilities, and establishing a more efficient freight system. The railway and marine sectors could play important roles in mid- and long-distance transport for bulk cargo, while new energy vehicles and conveyor belt systems (also known as belt corridors), should be prioritized for short-distance transportation.

#### **05 Exploring intelligent and innovative solutions for managing vehicle emissions in the era of the IoT and big data**

Deep emission reduction relies on monitoring of vehicle emissions, real-time inspection of road traffic, and intelligent transport management. The technologies combining intelligent sensing and big-data, such as remote OBD integrated with link-based emission inventories, will play critical roles in future smart management systems. Cities will increasingly adopt powerful advanced technologies, such as 5G, artificial intelligence, big data, and cloud computing to develop innovative, green and low-carbon high-efficiency transportation modes. Comprehensive supervision and an optimized transportation system that integrates vehicles, roads, and cloud data can be expected. Upgrading existing platforms which apply a “sensing-decision” methodology to incorporate “digital, internet-connected, and intelligent” technology, will provide a smart path for improving air quality and achieving carbon peak and neutrality targets.

# A Retrospective and Prospective Study on 20 Years' Mobile Source Emissions Control in Megacities of China

## Contact

### 📍 ADDRESS

School of Environment, Tsinghua University  
Beijing, 100084, China

### ✉ E-MAIL

ywu@tsinghua.edu.cn  
wuxmeng@tsinghua.edu.cn