SEOUL BEIJING

Seoul-Beijing Bilateral Cooperation Research Report

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Seoul-Beijing
Bilateral Cooperation Research
Report 2025

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Executive Summary

Seoul - Beijing Bilateral Cooperation Research

In 2013, the Seoul Metropolitan Government (SMG) and the Beijing Municipal Government (Beijing) established the “Joint Committee of Exchanges and Cooperation” to promote systematic and pragmatic cooperation between the two capital cities. Expanding into the environmental sphere in 2015, this bilateral partnership created the Environment Team under the Joint Committee, strengthening cooperation in air quality management and climate governance.

To facilitate policy exchange within this framework, the ICLEI East Asia Secretariat has conducted two rounds of the Seoul-Beijing Bilateral Cooperation Research Projects from 2019 to 2021 and from 2021 to 2022. The first research featured a comparative analysis of the two cities’ overall air quality management, showcasing their approaches to boiler replacement, vehicle control, fugitive dust management, and seasonal air pollution measures. The second expanded its scope to climate change and carbon-neutrality policies in energy, building, and transport sectors, highlighting the importance of integrated management of air quality and greenhouse gas emissions. These two reports provided a systematic review of Seoul and Beijing’s efforts and achievements in air quality improvement and low-carbon transition, laying a strong foundation for subsequent collaboration.

Over the past decades, through ambitious policies and bold actions under initiatives such as Clear Seoul 2010, Clearer Seoul 2030 and the Blue Sky Protection Campaign, Seoul and Beijing have witnessed remarkable achievements in air quality management, significantly reducing fine particulate matter ($PM_{2.5}$), nitrogen oxides (NO_X), and sulfur dioxide (SO_2) levels. Building on these achievements and previous research, the current research examines the governance of volatile organic compounds (VOCs) of the two capital cities, which has become an increasingly critical focus in air pollution control in both Seoul and Beijing.

VOCs and Their Impacts

VOCs refer to a large group of organic chemicals with high vapor pressure and low water solubility, which enable them to evaporate easily into the atmosphere at room temperature. VOCs are predominantly emitted from anthropogenic sources. Industrial processes, such as petrochemical refining, chemical manufacturing and painting operations, are major contributing factors, where VOCs are released while using raw materials that contain volatile solvents, or emitted as byproducts during the process. Vehicle emissions are also considered as a significant contributor to VOCs emissions through the incomplete combustion of fossil fuels and the evaporation of gasoline. Additionally, the widespread use of solvents in household and commercial products leads to a large quantity of VOCs emissions. These daily used solvents include cleaning agents, adhesives, varnishes and personal care items like nail products, hair products and so on.

Once emitted, VOCs undergo complex photochemical reactions in the presence of NO_X in the air, leading to the formation of ground-level ozone and secondary organic aerosols. These reactions are central to the degradation of air quality in urban and industrialized regions and contribute indirectly to global warming. In addition, VOCs negatively impact human health, causing detrimental consequences. To be more specific, inhalation of VOCs and their reaction products leads to carcinogenic risks and the aggravation of respiratory diseases such as asthma and bronchitis. This is particularly harmful to children and the elderly, the most vulnerable group.

Given the severity of the problems, science-based, integrated and innovative policy interventions, along with comprehensive strategies, for VOCs reduction and governance are essential. This includes advancements in emission-monitoring technologies, optimization of industrial processes and structures, and stringent regulatory frameworks. As two of the megacities in East Asia that suffer from air pollution and its consequences, Seoul and Beijing have been making significant efforts to combat air pollution and improve air quality over the past decades.

This report aims to systematically review the latest policies and practices related to VOCs governance in both Seoul and Beijing, including regulatory development, effectiveness and outcomes of their VOCs governance policies and initiatives, and valuable experiences for international peer cities facing similar challenges. The findings are also expected to provide valuable insights to strengthen future city-to-city cooperation and policy references to other megacities.

Seoul

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With special thanks to the Climate & Environment Headquarters of the Seoul Metropolitan Government for providing background materials and data updates, and for offering technical comments during the drafting of this chapter.

1. Background

Seoul, the capital of South Korea, is a densely populated metropolis with 9 million residents within just 605.2 km^2. The city envisions becoming a world-class city in all fields, including culture, environment, welfare, and economy. Its vision is to build a warm and people-centered city, a green city inspired by nature, a vibrant city and a historical and cultural capital. To realize this, Seoul has implemented a wide range of strategic projects.

To address the air quality challenges posed by dense urbanization and rapid industrialization, Seoul has taken multiple initiatives over the past two decades to reduce and prevent air pollution. Seoul's air quality improvement policy has been evolving in a more integrated manner for Seoul's long-term sustainable development. A key moment in this shift was the enactment of the **Special Act on Air Quality Improvement for the Capital Region** in 2003, which fostered collaborative air governance encompassing Seoul, Incheon, and Gyeonggi Province.

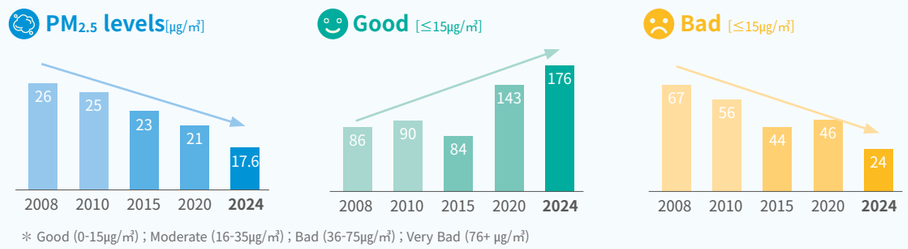
In the years that followed, Seoul made continuous efforts to reduce air pollution to meet different priorities. In 2007, Seoul launched the **Clear Seoul 2010 Plan** which focused on mobile sources by converting diesel buses to compressed natural gas (CNG) ones, achieving diesel-free public buses. Seoul also actively promoted the installation of emission-reduction devices on old diesel vehicles. In 2019, Seoul implemented emergency measures to reduce fine dust emissions, alleviating concentrations through centralized management over a short period of time.
The Low Emission Zone in the Green Transport Zone was introduced to permanently restrict grade 5 diesel vehicles. In addition, aged vehicles were restricted during periods of high fine dust concentration through **Emergency Reduction Measures for High Fine Dust Concentration.** Recognizing the seasonal nature of air pollution, Seoul has introduced the **Seasonal Fine Dust Management System**, implemented annually from December to March since

Seoul's Clear Sky

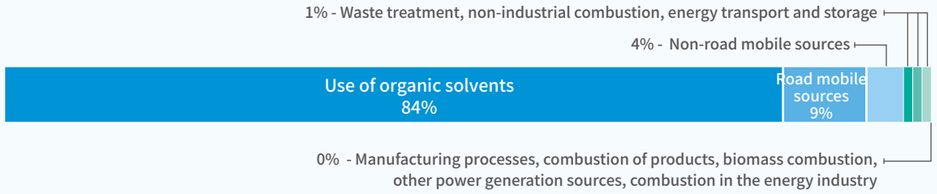
Emergency Reduction Measures for High Concentrations of Fine Dust

Source | Seoul Metropolitan Government

▪ **$PM_{2.5}$ Levels in Seoul 2008–2024** Source | Seoul Metropolitan Government



▪ **VOCs emissions by Source in Seoul** Source | The Seoul Institute



2020. This Seasonal Management System includes targeted winter actions such as construction site special inspections and further restrictions on older vehicles. Most recently, from 2022, Seoul has been pushing forward the **Clearer Seoul 2030 Roadmap** with an ambitious target to reduce annual $PM_{2.5}$ concentrations to 13 μg/m^3 by 2030.

These efforts have delivered tangible results. Between 2008 and 2024, Seoul's annual average $PM_{2.5}$ concentration dropped from 26 μg/m^3 to 17.6 μg/m^3—the lowest level recorded since monitoring began. Additionally, other pollutants like NOx and sulfur oxide (SOx), have consistently decreased, reflecting improvements across both stationary and mobile emission sources.

With steady reductions in major air pollutants including $PM_{2.5}$, NOx, and SOx, ozone and VOCs became primary concerns of air pollution in Seoul, particularly during the summer months when sunlight accelerates photochemical reactions.

According to Seoul's official data in 2024, Seoul's main source of VOCs emissions is solvent use, accounting for nearly 85% of

Euljiro Printing Alley

Source | Seoul Metropolitan Government

Seoul's total VOCs emissions—significantly higher than in other major cities such as Busan (77.8%) and Incheon (51.9%). In addition to large-scale solvent use in industrial processes, small-scale solvent use for laundry, printing and painting holds a significant share of VOCs emissions. These activities are mainly concentrated in older neighborhoods like Jung-gu, Euljiro, and the Sewoon District. These areas host dense clusters of small and medium-sized enterprises (SMEs) engaged in printing, metalworking, surface treatment, and dry cleaning, many of which are located near residential zones.

To tackle seasonal peak emissions and emissions from scattered, often under-regulated sources, Seoul is proactively adopting targeted and seasonal interventions, such as focused **inspections in high-emission districts, support for SMEs to adopt low-emission equipment and eco-friendly solvents**, and the promotion of low-VOC products across industries. As a result, between 2018 and 2022, Seoul successfully reduced VOC emissions by 25%, from 73,118 tons to 54,677 tons.

2. Policy Analysis

2.1 Evolution of VOCs Control Policies and Regulatory Frameworks

Seoul's approach to managing VOCs has evolved from broad, industry-wide regulation to more localized and sector-specific strategies. This shift reflects Seoul's deeper understanding of VOCs' role in ozone formation, their health impacts in dense urban areas, and the growing need to control emissions from diverse and diffuse sources. This transition laid the groundwork for a more adaptive framework to address localized emission hotspots and seasonal pollution peaks effectively.

Rather than relying solely on traditional end-of-pipe controls, Seoul turned to preventive strategies such as encouraging the use of substitute materials e.g., low-VOCs alternatives, conducting targeted seasonal inspections, and localizing enforcement.

· Phases of VOCs Control Policy Evolution

Phase 1 **Monitoring & Regulation on Major Sources** 1997-2006

- **Key Actions** Designated air quality control zones; specified the responsibilities of businesses (e.g., gas stations, dry cleaning facilities) on VOCs pollution prevention and control
- **Shift** From passive responding to VOCs pollution to active reduction through abatement requirements

Phase 2 **Expansion to Urban SMEs** 2007-2016

- **Key Actions** Extended VOCs regulations to small businesses (e.g., printing, drying); introduced vapor recovery systems at gas stations; and established specific standards for VOCs content in printing
- **Shift** From major industrial sources to diffuse urban emitters

Phase 3 **Enhanced Standards & Localized Management** 2017-Present

- **Key Actions** Expanded the supply and dissemination of low-VOCs products; urged the establishment of a VOCs management system for consumer products
- **Shift** From end-of-pipe control approach to proactive and localized management

2.2 Governance and Control Measures

Building on its evolving policy framework, Seoul has developed a comprehensive set of implementation strategies to translate regulatory intent into tangible outcomes. These strategies are structured around three main pillars: seasonal control measures in summer, routine interventions, and capacity-building programs, especially when the likelihood and frequency of ozone pollution are higher.

1) Seasonal Control Measures (May-August): Policies in the Industrial, Transportation, and Construction Sectors

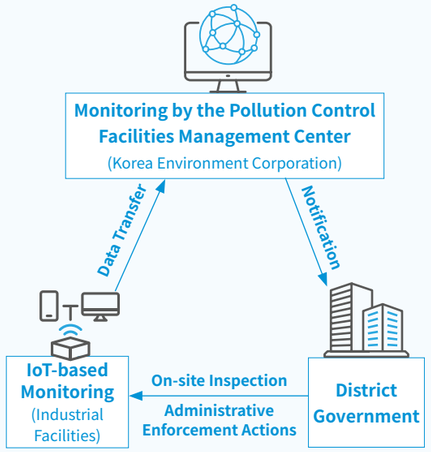
In summer, the warmer temperature in Seoul increases the evaporation of VOCs from various sources and accelerates photochemical activities, leading to higher VOCs and ozone pollution. Thus, from May to August each year, Seoul undertakes targeted activities to reduce VOCs emissions and prevent ozone pollution across three major sectors: industry, transportation, and construction. Strict regulatory enforcement is complemented with technical and financial support, especially in high-risk areas where emissions tend to concentrate.

Industrial Sector: Targeting VOCs from both Formal and Informal Sources through Technical and Financial Support

In districts like Jung-gu and Gangseo-gu, small-scale emitters such as dry cleaners, printers, and automobile repair shops, are responsible for a substantial share of VOCs emissions. Since many of these SMEs lack the capacity to implement advanced abatement systems on their own, Seoul employs a dual approach of supervision and targeted support to address VOCs emissions from both formal and informal sources.

For small size units emitting less than 10 tons/year, Seoul supports the deployment of real-time IoT-based monitoring systems which provide continuous data on VOCs release. To facilitate uptake, the city

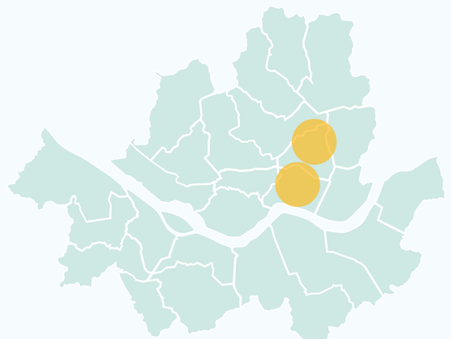
▪ **IoT Real-time Monitoring System**
Source | Seoul Metropolitan Government



subsidizes up to 90% of installation costs, scheduling for deployment in all small-scale units in Seoul by December 2026.

Seoul also conducts targeted crackdown on **informal operations** such as unlicensed auto painting shops, where fugitive emissions are common. These efforts are often triggered by citizen reports and play an important role in addressing uncontrolled emission sources that fall outside the formal regulatory system.

▪ **Unregistered Painting Facilities Concentrations** Source | Seoul Metropolitan Government



Unlicensed Painting Facility

In addition, Seoul is actively tackling emissions from **regulated facilities,** particularly gas stations, which account for 94% of VOCs emissions facilities. Seoul, in collaboration with the Korean Environment Corporation(K-eco), provides technical assistance to underperforming stations, including leak detection, pressure testing, and staff training.

Technical Support for VRS at Gas Station

Recovery Rate Inspection

Pressure Reduction, Leakage Inspection

Source | Seoul Metropolitan Government

Transportation Sector: Strengthening Inspections to Reduce Mobile Emissions

To ensure the integrity of mobile source emissions control, the city conducts joint inspections of private emissions testing facilities to ensure accurate calibration and staff qualifications. These audits are especially important in dense districts where inaccurate testing could result in excessive emissions from noncompliant vehicles.

Roadside Monitoring & Idling Control

Source | Seoul Metropolitan Government

Construction Sector: Combining Mandatory Requirements with Voluntary Efforts

VOCs emissions from construction activities, particularly exterior painting and paving activities, account for a notable share of urban VOCs emissions. To address this, Seoul mandates the use of low-VOCs and eco-certified materials at large-scale construction sites (exceeding 100,000 m^2 in area), and is working to expand this requirement to all public-sector projects. These efforts will contribute to reducing VOCs emissions, particularly in Seoul's numerous redevelopment and reconstruction zones, aiming to reduce the risk of ozone formation. During the high ozone concentration period (May to August), on-site inspections are conducted at public construction sites, recommending the use of low-VOC materials, and imposing restrictions on outdated machinery and flexible working hours to avoid midday operations when ozone formation is most likely.

The five equipment types summarized in the table below are subject to restrictions on the use of outdated construction machinery.

Reflecting Seoul's commitment to improving air quality, this policy aims to continuously enhance VOCs emission control in the construction sector through the management of material use and equipment operation.

▪ **Restrictions on the Use of Old Construction Machinery** (5 types)

3 types of on-road use			2 types of non-road use	
Dump trucks	Concrete mixer trucks	Concrete pump truck	Excavators	Forklifts
				

Source | Seoul Metropolitan Government

2) Routine Measures: Policies Targeting Domestic Sources

While Seoul's seasonal control measures emphasize the efforts especially needed in the summer season, its routine control measures aim to address VOCs emissions from everyday and diffuse sources, which collectively contribute significantly to urban air pollution and require tailored and source-specific responses.

In Seoul, small dry cleaning businesses, especially those operating in mixed-use areas, remain a persistent yet under-regulated source of VOCs. Currently, only 0.5% of dry cleaners in Seoul are subject to VOCs regulations, leaving the vast majority of emissions unmanaged. To address this gap, Seoul is supporting the adoption of more than 90% high-efficiency solvent recovery systems, including solvent recovery dryers and integrated washer-dryer machines.

Eco-Washer

Solvent Recovery Dryer

Source | Seoul Metropolitan Government

This initiative not only contributes to lower local VOCs emissions and operational costs but also reduces odor-related complaints—delivering both environmental and socio-economic benefits.

In addition to managing VOCs emissions resulting from solvent use from dry cleaning activities, Seoul actively promotes and mandates the utilization of low-VOCs ink for all public-sector publications, enforced through semi-annual compliance audits for continuous management of VOCs emissions.

Beyond efforts in the industrial and public sectors, Seoul also focuses on VOCs emissions from consumer goods such as sprays, air fresheners, and other household products. Although the VOCs content of these consumer products is relatively low, the widespread use of these consumer products in residential and commercial areas results in substantial cumulative emissions. However, despite being a primary source, this category has faced limited regulatory oversight.

As the need for safe product use and a market transition to address the regulatory blind spots increases, Seoul is proactively promoting public-private cooperation through partnership with the Consumer Chemical Safety Commitment Council, a multilateral body composed of the Ministry of Climate, Energy and Environment, Korean Environmental Industry & Technology Institute (KEITI), private companies and civic groups. The city plans to formalize their mutual efforts

for the production and expanded use of low-VOCs products through a future Memorandum of Understanding (MOU). This partnership aims to increase the visibility and accessibility of low-VOCs alternatives across the entire consumer product market.

One of the initiatives is to provide support programs enabling citizens to select and use VOCs-safe consumer goods in their daily lives, thereby establishing a culture of practical application and encouraging voluntary participation in VOCs reduction activities.

In addition, Seoul is pursuing a long-term transition away from internal combustion engine (ICE) vehicles, beginning with restrictions on grade 5 diesel vehicles in 2026 and culminating in a complete phase-out by 2050. Key actions include expanding Low Emission Zones (LEZ); providing financial incentives for electric vehicle (EV) adoption; and extending early scrappages. To further accelerate the shift to clean transportation, Seoul is increasing support for EVs, with a focus on delivery services, taxis, and public fleets. Support includes expanding EV charging and hydrogen fueling infrastructure and offering preferential treatment for zero-emission vehicles within LEZs.

3) Capacity Building

To ensure the long-term effectiveness of its VOCs governance strategies, Seoul is investing in building its scientific, institutional, and international capacities. These efforts aim to reinforce evidence-based policymaking, strengthen interregional cooperation, and promote global partnerships to address the complex challenges of ozone and VOCs pollution.

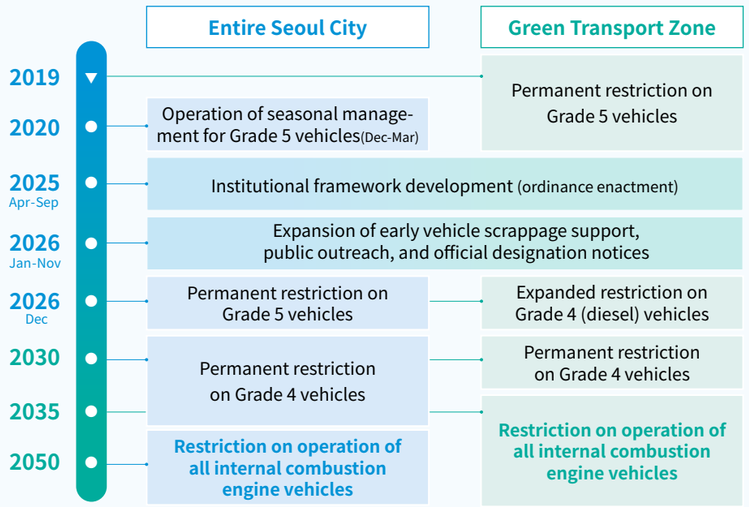
Seoul is expanding its understanding of the formation and transport of ozone and its precursors—VOCs and NO_X—by improving regional monitoring and conducting emissions modeling. According to the 2025 Action Plan under **Special Measures for High-Concentration Ozone Management**, a citywide ozone source analysis will be launched to refine Seoul's emission inventory and support more targeted control measures in the near future.

Recognizing that air pollution transcends administrative boundaries, Seoul is deepening collaboration with Gyeonggi Province and Incheon City. Through the Capital Region Air Quality Council, the three governments hold regular policy dialogues and implement joint ozone seasonal controls to address shared air quality challenges.

Seoul is also expanding its global engagement by partnering with peer cities e.g. Beijing to exchange best practices through joint research and peer learning at international forums. These collaborations help Seoul stay at the forefront of innovation and policy development in urban air quality.

Through these capacity-building initiatives, Seoul is laying the foundation for sustained and scalable air quality improvements. By enhancing data accuracy, strengthening regional coordination, and fostering international cooperation, the city is reinforcing its ability to respond to emerging air pollution challenges—and positioning itself as a global leader in clean air governance.

▪ **Seoul City's Roadmap for ICE Vehicle Phase-Out** (Draft)



3. Case Study:

Promoting the Reduction of VOCs from Unrestricted Emission Sources

3.1 Background and Objectives

In Seoul, there are a total of 2,389 air emission facilities. Among these, 50 facilities fall under Class 1 to 3, while 2,339 facilities are classified as Class 4 and 5. Facilities classified as Class 4 and 5, which generate less than 10 tons of air pollutants annually, constitute the majority.

· Classification of Air Pollutant-emitting Facilities in Seoul

Total Facilities	Class 1 (≥80t)	Class 2 (20-80t)	Class 3 (10-20t)	Class 4 (2-10t)	Class 5 (<2t)
2,389	17	12	21	786	1,553

Facilities subject to emission controls are designated and managed under the Enforcement Decree of the Clean Air Conservation Act, with specific VOCs facilities designation and public notification by the Ministry of Environment. Specifically, regulated business facilities are managed through support programs that replace aging facilities, and through compliance checks that ensure vapor recovery systems for solvents and that pollution prevention facilities are operating normally.

However, a challenge Seoul faces in VOCs emission control is that the city possesses numerous facilities that fall below the regulatory threshold. Specifically, small-scale organic solvent usage facilities (such as painting, printing and dry cleaning) are

· Non-regulated Sites emitting VOCs

Category	Total	Dry Cleaners	Printing Shops	Painting Facilities	Gas Stations
Total number of sites	**14,564**	6,286	6,801	1,013	464
Number of regulated sites	**1,069 (7.34%)**	27 (0.43%)	1 (0.01%)	591 (58.34%)	450 (97%)
Regulatory threshold	-	Processing capacity ≥ 30 kg/day	Total volume ≥ 1 m^3	Chamber volume ≥ 5 m^3	Storage volume ≥ 20 m^3

Source | Seoul Open Data Plaza, 2024, Places of business for Air Pollutant Emitting Business Sites (as of Dec 2024)

largely excluded from official regulatory oversight, which complicates effective management and inspection. This situation necessitates a proactive response targeting these non-regulated units.

3.2 Implementation

Recognizing the complexities and significance of regulating and controlling the VOCs emissions from unrestricted sources, Seoul adopts a complementary and targeted approach, particularly in the summer season. Seoul established and implemented a **VOCs Source Concentration Management Plan** from 2022 to 2024. The core emission sources managed under this plan included painting (automotive and architectural), printing and dry cleaning facilities.

In addition to technical support that improves equipment and abatement capacity, the government actively promotes the application of water-borne paints and eco-labeled inks, and raises citizens' awareness of their use. The detailed initiatives for each source are as follows.

Supporting Water-based Painting Equipment for Automotive Facilities

To facilitate the transition and expansion of water-based automotive repair coatings, in 2023, Seoul provided specialized equipment (spray guns, electronic scales and dryers) for water-based coating to comprehensive automobile maintenance facilities (1,000m^2 or more) and small automobile maintenance facilities (400m^2).

Spray Gun(Printing Gun)

Electronic Scale

Dryer

Cleaner (Spray Gun)

Source | Seoul Metropolitan Government

Using Eco-Label Paint in Public Construction Sites

Since 2022, Seoul has continuously encouraged the use of eco-label certificated painting for coating work at construction sites of the city and its affiliated institutions, aiming to establish the public sector as a leader in low-VOCs product use. The certification criteria for these paintings are as follows:

· Eco-label Certified Standard

Category	General Painting Standard (g/L)	Eco-label Certified Standard (g/L)
Concrete (Oil=based Exterior)	≤ 400 - 450	≤ 200
Steel (Excl. Lacquer)	≤ 440 - 470	≤ 300
Wood (Excl. Oil/Lacquer)	≤ 450	≤ 300

Printing: Promoting Low-VOCs Inks in Public Printing

Regarding Low-VOCs ink, Seoul is pushing for the mandatory use of eco-friendly inks for publications subject to public relations material review, aiming to lead the use of low-VOCs products in the public sector. Eco-friendly ink types include soy-based ink, eco-label certified ink and solvent-free ink.

Dry Cleaners: Granting VOCs Reduction Equipment

In the cleaning and drying sector, Seoul is actively implementing a support program for the installation of VOCs reduction facilities in dry cleaners. Since 2023, the city has been supporting the installation of eco-friendly washing machines and solvent-recovery dryers in small dry cleaners with a processing capacity under 30kg. The eco-friendly washing machine is an integrated washer and dryer with a solvent recovery rate of 90% or higher for dry cleaning solvents. In tiny shops where full machine replacement is not feasible, the recovery dryers are installed.

3.3. Outcomes

To assess the effectiveness of the policy measures and inform further policy improvement, the Seoul Metropolitan Government conducted a quantitative analysis in 2025 to evaluate the emission reduction effects from its VOCs reduction project targeting non-regulated facilities. This analysis evaluates changes in VOCs emissions and reduction effects by support type, and derives tangible policy outcomes. Detailed results are as follows.

Reduction in VOCs Emissions

The official analysis shows that following the support programs for water-based **painting equipment** in 89 repair shops in 2023, the annual VOCs emissions from oil-based coatings decreased from 12,503kg to 5,557kg. This represents an estimated 56% reduction, calculated based on VOCs content, conversion rate and equipment supply. Regarding construction painting facilities, a positive outcome was observed after the city mandated the use of eco-label certified painting in public construction

projects. As the usage of eco-label painting increased from 81.3% in 2022 to 87.4% in 2024, the annual VOCs emissions decreased from 128,437kg to 98,450kg, achieving a reduction of approximately 23%. This is calculated based on construction area, printing usage and certified eco-label printing ratio.

In municipal operations, the proportion of eco-friendly ink used in **printing** has risen from 12.6% in 2022 to 31.9% in 2024, with further adoption after additional institutional reforms. Annual VOCs emissions were reduced from 4,040kg to 3,873 kg.

Between 2023 and 2024, 36 **dry cleaners** has installed VOCs emission reduction equipment such as eco-friendly dry-cleaning machines and solvent-recovery dryers, which resulted in a 58% annual VOCs reduction from 21,793kg to 9,192kg, calculated based on solvent purchased reduction and unit emission factors.

Reduction in Hazards and Health Risks

In addition, to evaluate the reduction effects and changes in toxicity resulting from switching to low-VOCs products for key items, Seoul conducted complementary analysis based on each product's **Material Safety Data Sheet** (MSDS). This included examining VOCs composition, toxicity information, and legal regulatory requirements.

First, in the aspect of VOCs' composition, traditional oil-based products showed high VOCs content, mostly ranging from 58% to 120%. Whereas the water-based products introduced through the support program had 21% to 43% of VOCs content, indicating a substantial reduction in unit emission per product.

In terms of hazard identification, oil-based products contained numerous substances associated with oral, dermal and inhalation toxicity - up to nine such substances in construction paintings and four in printing inks. In contrast, the number of toxic substances identified under the same criteria was significantly lower in water-based products.

Moreover, most oil-based products are regulated under multiple regulations including Occupational Safety and Health Act, Chemical Substances Control Act, and Clean Air Conservation Act, whereas water-based products generally fall outside these scopes or contain fewer regulated chemicals.

In summary, this analysis indicates that converting existing oil-based products to water-based alternatives via the support programs is expected to yield highly positive environmental and health effects. It not only decreases the number of toxic and legally regulated substances with harmfulness but also reduces the total VOCs emissions significantly .

4. Reflections and Recommendations

1) Regulation and Incentive Policy for the Paint Business

Under the current Clean Air Conservation Act, VOCs content standards are primarily regulated at the supplier level, including paint manufacturers and sellers. However, Seoul has no direct legal sanctions for consumers of oil-based paints yet, which limits the effectiveness of on-site inspections and enforcement.

To improve administrative efficiency and strengthen compliance, it is recommended to implement institutional reforms that introduce consumer-side restrictions on VOCs use, mandatory training requirements and simplified sampling procedures during on-site inspections of painting facilities. These revisions should also include administrative measures for violations, such as suspension orders.

Given that legal reform can be a long-term process, a short-term strategy should focus on inducing the transition to eco-friendly paintings through voluntary industry participation and incentives, such as awards for exemplary businesses, to enhance acceptance and rapid adoption.

2) Development of Practice-Oriented Education Materials for Small Businesses

Currently, on-site understanding of water-based paint conversion remains limited. Existing outreach and equipment-support programs are often theoretical or policy-centered, reducing their practical impact.
To address this gap, it is suggested to develop hands-on, practice-oriented training programs covering the installation and operation of air pollution control equipment, as well as practical workshops for water-based paint conversion.

3) Scale-up Support for Eco-friendly Equipment in Small Business

The current equipment support programs (e.g., for the auto repair business) have shown limited effectiveness due to insufficient demand and a restricted scope of support. To actively facilitate the transition to water-based paintings and maximize the effect of VOCs reduction, the city should establish a comprehensive and scalable support system that covers both high-cost equipment and small-scale tools. Such a system would make eco-friendly conversion more feasible across a wide range of businesses and facility sizes.

· Regulation Articles on Clean Air Conservation Act

Act	Violation	Penalty
Article 44 (2) 3-4	· Supply or sell paintingsexceeding VOCs standards	· Order to halt supply or sale, or recall paintings
Article 91 (3) 2-5	· Supply or sell paintings exceeding VOCs standards · Violate the order to halt supply/sale or recall coatings.	· Imprisonment for up to 1 year or a fine up to 10 million KRW

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- SPECIAL ACT ON THE IMPROVEMENT OF AIR QUALITY IN AIR CONTROL ZONES 2021 (KR1.)

Beijing

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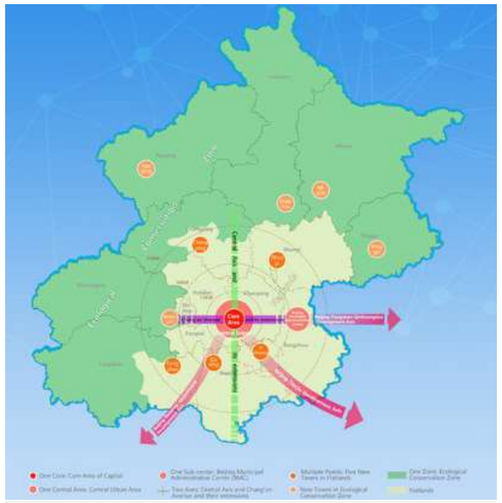
1. Background

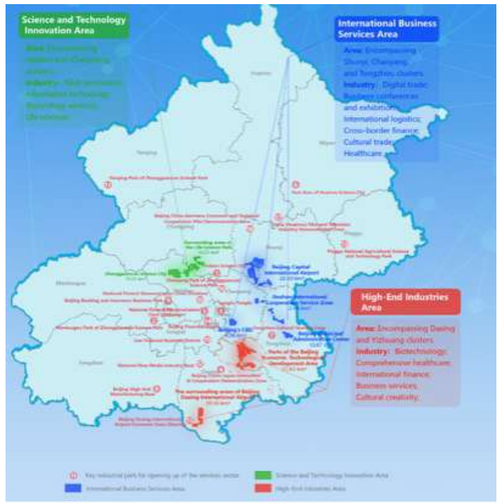
Beijing, the capital of the People's Republic of China, serves as the nation's political, cultural, and technological hub. As a megacity with over 21.8 million residents and a land area of 16,410 km^2, Beijing has experienced rapid urbanization and economic transformation in recent decades.

Beijing's economic structure has undergone significant adjustment over the past decades, transitioning from a secondary industry-dominated economy to a tertiary industry-dominated economy. According to Beijing's statistical bulletins on national economic and social development in 2024, the tertiary sector accounted for 85.3% of the city's GDP. Nowadays, finance, information technology, scientific research and development, cultural and creative industries, and professional services serve as Beijing's key growth drivers. The secondary sector, which encompasses manufacturing and construction, continues to decline and now accounts for less than 15% of Beijing's economic output. Specifically, industrial activities have been gradually relocated out of the central urban area since the 2000s, especially those associated with high pollution and high energy consumption.

Despite the transformation, legacy sources of emissions, including construction activities, transportation, residual small-scale industrial operations in peri-urban areas, as well as other non-restricted emissions, continue to pose challenges to environmental management, particularly with regard to air quality control.



Beijing Industrial Master Plan (2016-2035)



Beijing Industrial Map issued in 2024

Source | Beijing Municipal Commission of Development and Reform

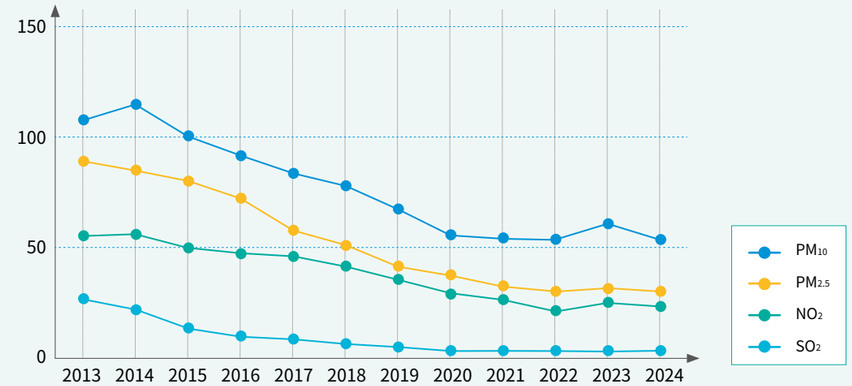
Beijing has made significant efforts to improve its air quality in recent years, especially since the launch of **Beijing's 2013-2017 Clean Air Action Plan** in 2013, with specific annual clean air plans developed each year. In 2014, Beijing enacted **Regulations of Beijing Municipality on the Prevention and Control of Atmospheric Pollution,** which is the first local regulation in China setting the control of fine particles ($PM_{2.5}$) as the primary objective. From 2016 to 2017, two key documents were introduced to outline Beijing's strategies to combat air pollution in the Beijing-Tianjin-Hebei Region, namely **Implementation Plan for Beijing Municipality on the Implementation of the Enhanced Measures for Air Pollution Prevention and Control in the Beijing-Tianjin-Hebei Region (2016-2017)** and the **Detailed Implementation Plan for Beijing Municipality on the Action Plan for Comprehensive Air Pollution Control during the 2017-2018 Autumn and Winter Season.** These plans focus on reducing emissions from various sources, including industrial activities, transportation, and residential heating. With urban operations and daily life activities becoming the primary sources of air pollution, the city developed the **Three-Year Action Plan for the Blue Sky Protection Campaign in Beijing** in 2018, outlining a comprehensive roadmap for air pollution control in Beijing. Based on the progress made in the previous years, the city's air pollution control efforts have been upgraded from the "1 microgram" campaign to the "0.1 microgram" campaign, requiring more scientific measures and more meticulous control.

Key strategies are in place across multiple sectors with tangible outcomes. In the industrial sector, over 2,600 polluting enterprises have been closed or relocated out of the city since 2013, particularly in the cement, chemical, and metallurgy sectors. In the transportation sector, the city has implemented increasingly strict emission standards for in-use vehicles, while actively promoting new energy vehicles and phasing out older high-emission vehicles. As of April 2025, the number of new energy vehicles in Beijing has exceeded one million. In the construction sector, real-time monitoring and stricter compliance inspections significantly contributed to the reduction of fugitive dust emissions from construction sites and roads. Meanwhile, the city also put a lot of effort into transitioning the energy structure. By the end of 2023, approximately 1.38 million households in the city will have implemented the "coal-to-clean energy" program, with 93% of villages and 96% of rural households achieving clean heating with cleaner alternatives, such as electricity and natural gas.

Following the implementation of multi-sectoral strategies, the city's air quality has improved significantly, with a notable reduction in multiple air pollutants. According to the 2024 Beijing Municipal Environmental Protection Bulletin,

▪ **Trend of Annual Average Concentrations of Major Air Pollutants from 2013 to 2024**

Source | 2024 Beijing Municipal Environmental Protection Bulletin



According to the Ambient Air Quality Standards (GB3095-2012), the Grade II limit values for six major air pollutants are as follows : $PM_{2.5}$: 35 μg/m³; SO_2: 60 μg/m³; NO_2: 40 μg/m³; PM_{10}: 70 μg/m³; CO (24-hour average): 4 mg/m³; O_3 (8-hour average): 160 μg/m³.

$PM_{2.5}$ has dropped by 65.9% since 2013. Specifically, annual concentrations fell from nearly 90 μg/m³ in 2013 to around 30.5 μg/m³ in 2024, meeting China's national standard for the first time in 2021. Other pollutants have also decreased significantly: PM_{10} by 50%, NO_2 by 57.1%, and SO_2 by approximately 88.7% between 2013 and 2024 .

With significant improvements achieved in controlling $PM_{2.5}$ and other major air pollutants, governance of VOCs emissions, which lead to ozone formation and severe public health challenges, has gained substantial attention in recent years. Initially, Beijing's efforts in VOCs governance have been focused on key industries, such as the industrial sector, the transportation sector, and several solvent-intensive industries. Particularly, the city has actively promoted industrial upgrading and restructuring, and the construction of end-of-pipe treatment facilities. Subsequently, with a significant reduction in organized emissions, measures have been gradually expanded to include the control of unorganized emissions. Through these comprehensive sector-targeted measures, Beijing has achieved a significant reduction in VOCs emissions. According to the preliminary analysis released by Beijing Municipal Ecology and Environment Bureau, anthropogenic VOCs emissions in 2023 in Beijing decreased by 64.6% compared to 2013.

2. Policy Analysis

2.1 Evolution of VOCs Control Policies and Regulatory Frameworks

Over the past decade, Beijing has gradually strengthened its efforts to control VOCs, in response to growing public health concerns and the urgency of controlling ozone pollution. The National 12th Five-Year Plan for Environmental Protection (2011-2015) proposes to implement comprehensive control of multiple air pollutants and strengthen the control of VOCs emission at the national level. In response to the national plan, Beijing has formulated and updated the **List of Key Monitored Enterprises in Beijing during the 12th Five-Year Plan Period** to strengthen supervision of key pollution sources in the early 2010s. The list included a total of 418 key monitored enterprises, with 64 enterprises emitting VOCs. From 2015 to 2017, Beijing Municipal Ecology and Environment Bureau organized the drafting of **local VOCs emission standards** targeting various industries, in accordance with the requirements of the Beijing Clean Air Action Plan. In this stage, VOCs control in Beijing mainly focused on large industrial sources, especially in sectors like printing, furniture manufacturing, and painting.

Following these initial efforts, the policy frameworks of VOCs governance became more detailed and included a wider range of industries, particularly with the introduction of national plans like the 13th Five-year Plan for Economic and Social Development (2016-2020) and local Clean Air Action Plans. Beijing also clearly defined its **emission reduction targets** for this period, aiming to reduce NO_X and VOCs by 20% by 2020 compared to 2017 levels. To achieve the specific target, the city implemented a series of measures across multiple sectors. Measures for this phase include implementing classified control of VOCs emissions, formulating or revising a set of **stricter emission standards** for pollutants, e.g., limits on VOCs content in products, as well as **monitoring methods and technical specifications,** and actively promoting the inclusion of VOCs in the scope of taxation. In addition to restrictive measures, Beijing is also actively providing technical and financial support to encourage various industries to take proactive measures to reduce VOCs emissions.

Since 2021, the city has focused on building a more comprehensive VOCs management system and has also set a clear emission reduction goal in accordance with the requirements listed in the national Action Plan for Continuous Improvement of Air Quality, aiming to cut total VOCs emissions by 10% by 2025 compared to 2020 levels. This requires a combination of mandatory measures and voluntary efforts, such as real-time monitoring at major facilities, regular inspections for strict compliance, and purchasing low-VOCs products in daily life. What's more, with the support of advanced low-VOCs technologies, districts and industrial parks have strengthened their capacity to control VOCs emissions, showing a shift toward full-process control, actively addressing unorganized and fugitive emissions.

Overall, Beijing's VOCs policies have evolved from basic industrial regulation to a more integrated approach, combining standards, monitoring, and technological improvements to address diverse and diffuse emission sources.

In the following section, Beijing's progress in reducing VOCs emissions in different sources will be analyzed, mainly focusing on the combination of strict local standards with active supervision and behavioral guidance.

2.2 Policy Governance and Control Measures

1) Industrial Sources

Beijing's VOCs governance in the industrial sector primarily targets the petrochemical industry, printing sector and other high-VOCs-emission industries.

Petrochemical Industry

The **petrochemical industry** is a major source of VOCs emissions in Beijing. The emissions mainly come from the storage, transport, processing, and leakage of raw materials and products. Since the early 2010s, Beijing has continuously strengthened VOCs control measures in this industry. First of all, it requires that the enterprises enhance the maintenance of all types of facilities involved to ensure that organized emissions meet standards.

Second, for those processes prone to unorganized emissions, such as storage and transportation, enterprises should promptly replace valves, pumps, compressors, and other devices easily leading to leakages. Concurrently, dynamic leak detection and repair (LDAR) programs are implemented to control leakage at all sealing points.

Emission Standards of Air Pollutants for Petroleum Refining and Petrochemicals Manufacturing Industry (DB11/447-2015)

Emission Standards for Air Pollutants of Miscellaneous Organic Chemicals Manufacturing (DB11/1385-2017)

Source | Beijing Municipal Ecology and Environment Bureau

For instance, the Beijing Municipal Environmental Protection and Ecological Construction Plan for the 13th Five-Year Plan Period(2016-2020) set strict control requirements on unorganized emissions and limiting leakage rates at all sealing points to below 1%. Besides, to prevent and avoid abnormal emissions, the management systems are continuously improving to control VOCs emissions during startup, shutdown, maintenance, and abnormal operations of petrochemical production facilities. The **Summer Campaign on VOCs Control** launched in 2024 further strengthened the reduction of unorganized emissions from key enterprises in the petrochemical industry, focusing on storage tanks and deep treatment of exhaust gas.

In addition, Beijing has introduced stricter air pollutant emission standards built on national standards, in line with its stringent emission reduction targets and advanced capacity. These local standards include the **Emission Standards of Air Pollutants for Petroleum Refining and Petrochemicals Manufacturing Industry (DB11/447-2015) and the Emission Standards for Air Pollutants of Miscellaneous Organic Chemicals Manufacturing (DB11/1385-2017)**. DB11/447-2015 stipulates that for refining and petrochemical industry equipment, the leakage detection value for pumps or compressors handling VOCs gases or liquids is 1,000 μmol/mol, which is significantly lower than the national standard (GB 31570-2015) of 2,000 μmol/mol.

Printing Industry

The printing industry is another key industry of Beijing that contributes substantially to VOCs emissions. In 2023, printing companies in the city generated over 24 billion RMB revenue. However, the industry involves extensive use of organic solvent, such as printing inks, adhesives, and cleaning agents, which emit significant amounts of VOCs during production.

In 2013, Beijing launched a special environmental protection campaign to rectify illegal emissions and safeguard public health, mandating enforcement inspections in the printing industry. The campaign strengthened environmental supervision of VOCs emissions from key controlled processes in the printing industry, focusing on the installation and operation of waste gas collection and treatment facilities, and strictly investigating unorganized waste gas emissions.

Since 2016, the use of raw materials with low-VOCs content has been actively promoted. The city and its printing enterprises conducted a wide range of clean production audits to ensure the use of low-VOCs materials in the production process, controlling VOCs from diverse sources. Concurrently, efficient solvent recovery and exhaust gas treatment systems have been installed, showing the efforts to manage VOCs emissions through end-of-pipe treatment.

Meanwhile, Beijing has made substantial efforts to establish a high-standard VOCs emission standard system. In May 2015, Beijing issued the local standard, **Emission Standards of Volatile Organic Compounds for Printing Industry (DB11/1201-2015)**, which primarily sets content limits for raw and auxiliary materials, process requirements, and management standards for VOCs emissions in this industry. This standard is one of the first industry-specific VOCs emission standards in Beijing. To expand the scope of control, Beijing Municipal Ecology and Environment Bureau and the Municipal Market Supervision and Administration Bureau jointly issued the **Emission Standards of Air Pollutants for Printing Industry (DB11/1201-2023)** in April 2023, replacing the previous one. This reflects stricter pollution control measures for the printing industry, covering not only VOCs but also other air pollutants. The standard covers aspects from source control to end-of-pipe treatment, including both organized and unorganized emissions.

Emission Standards of Air Pollutants for Printing Industry (DB11/1201-2023)

Source | Beijing Municipal Ecology and Environment Bureau

Coating and Manufacturing Industries

The city also focuses on those industries that extensively use VOCs-containing raw and auxiliary materials or emit large amounts of VOCs, such as industrial coating and manufacturing. The results of the Beijing VOCs pollution source census indicate that among industrial sources in Beijing, industrial coating accounts for a significant proportion of VOCs emissions from solvent-using pollution sources. Enterprises in Beijing that engage in coating processes primarily use solvent-based coatings. However, the application levels of low-VOCs content coatings, such as high-solid coatings, water-based coatings, and powder, are not high. What's more, the coating processes primarily involve low-efficiency air spraying and manual brushing, while efficient techniques such as immersion coating, flow coating, roller coating, and electrostatic spraying account for a minimal proportion. As a result, the production process inevitably generates a large amount of VOCs. To address these issues, Beijing has issued an industry-specific local standard **Emission Standards of Air Pollutants for Industrial Surface Coating (DB11/1226-2015)**, strengthening control over VOCs emissions from industrial coating enterprises and minimizing VOCs emissions from industrial coating processes.

Essentially, the implementation of the standard guide industrial coating enterprises to adopt clean production processes, optimize coating processes and

Emission Standards of Air Pollutants for Industrial Surface Coating (DB11/1226-2015)

Emission Standards of Air Pollutants for Automotive Manufacturing Industry (DB11/1227-2023)

Emission Standards of Air Pollutants for Wooden Furniture Manufacturing Industry (DB11/1226-2015)

Source | Beijing Municipal Ecology and Environment Bureau

equipment, and install efficient and stable end-of-pipe treatment equipment.

According to the data released in 2022, the **automotive manufacturing industry** contributes approximately 20% of Beijing's industrial VOCs emissions, making it one of the city's primary focuses to control VOCs from industrial sources. Within this sector, vehicle assembly comprises over two-thirds of total VOCs emissions, while parts and accessories manufacturing, engine production, and vehicle modification collectively account for more than 30%. Since 2015, the vehicle manufacturing sector has implemented the **Emission Standard of Air Pollutants for the Painting Process of the Automobile Manufacturing Industry (DB11/1227-2015)**, while vehicle modification manufacturers and those producing parts and accessories with coating processes adhere to **DB11/1226-2015**. To consolidate previously fragmented control requirements for the automotive manufacturing industry, Beijing released the **Emission Standards of Air Pollutants for the Automotive Manufacturing Industry (DB11/1227-2023)** in 2023, on the basis of DB11/1227-2015, national standards and its technological capacity. Taking effect on January 1, 2024, DB11/1227-2023 refines requirements for VOCs-containing raw and auxiliary materials, adjusts organized emission control indicators, and specifies unorganized emission control requirements. Its implementation supports automotive manufacturers in advancing source substitution, enhancing the collection and control of fugitive emissions, and standardizing the operation and maintenance of end-of-pipe treatment facilities.

In addition to the automotive manufacturing industry, Beijing has also made efforts in controlling air pollutants such as VOCs and paint mist generated from the **wood furniture manufacturing industry.** As of 2015, Beijing had over 1,000 wood furniture manufacturers. To regulate the environmental practices of wood furniture manufacturers, the city established the **Emission Standards of Air Pollutants for Wooden Furniture Manufacturing Industry (DB11/1226-2015)**.

According to regulations, the use of oil-based coatings will be completely banned in Beijing's furniture manufacturing industry after 2017. This local industry-specific standard sets limits on VOCs content in raw and auxiliary materials used in the industry, along with process measures and management requirements, to control VOCs emissions at the source.

2) Transportation Sources

Among the anthropogenic VOCs emission sources in Beijing, transportation is another major emission source. Through optimizing motor vehicles' structures, Beijing has achieved a reduction in VOCs emissions from transportation over the past decade. The city has also made efforts targeting other major sources in the transportation sector, with a particular focus on fuel distribution and asphalt-related activities.

Fuel Distribution Industry

The fuel distribution industry involves sites and facilities such as gasoline stations, storage depots, and tanker trucks. VOCs are easily evaporated during storage, loading, and refueling processes. To address this issue, Beijing has been developing and updating its local emission standards focusing on this industry in recent years. In 2003, Beijing, the first city in China,

Emission Control and Limits of Vapor for Bulk Petroleum Terminals (DB11/206-2023)

Emission Control and Limits of Vapor for Road and Rail Tankers (DB11/207-2023)

Emission Control and Limits of Vapor for Gasoline Filling Stations (DB11/208-2023)

Source | Beijing Municipal Ecology and Environment Bureau

implemented three local standards for oil vapor emissions from storage depots, gasoline tankers, and filling stations. Since then, Beijing has effectively promoted comprehensive management of VOCs emissions throughout the entire process. According to official data, the oil recovery efficiency has exceeded 80% in 2024 compared to the level in 2003, achieving significant emission reduction benefits.

In 2023, Beijing revised the three standards for the third time to meet the city's updated air quality goals and to align with technological advancements. The newly released standards are **Emission Control and Limits of Vapor for Bulk Petroleum Terminals (DB11/206—2023)**, **Emission Control and Limits of Vapor for Road and Rail Tankers (DB11/207—2023)**, and **Emission Control and Limits of Vapor for Gasoline Filling Stations (DB11/208—2023)**. These standards feature tighter emission limits, enhanced leak detection protocols, and new requirements for online monitoring. Considering that high temperature accelerates the release of VOCs, corresponding measures have been adopted. Gas stations and oil storage facilities are requested to stagger fuel loading and unloading times during the summer and encouraged to refuel during night time.

Asphalt-related Industry

Asphalt is widely used in urban operations and requires high-temperature conditions for handling. Its production, transportation and paving processes all contribute to a high level of VOCs emissions. Recognizing these challenges, the city has developed several targeted measures to control emissions from asphalt-related activities. In 2022, Beijing issued the **Technical Guide for Green Evaluation of Asphalt Mixture in Beijing (BJJT/ 0066--2022)** , which guides the green evaluation and labeling of asphalt mixtures in the city. Accompanied by newly released local standards **Technical Requirement and Evaluation for Green Production of Asphalt Mixing Plants (DB11/T 2424-2025)**, this industry-specific guide stipulates various measures for VOCs emissions reduction in the asphalt sector, covering different processes. They facilitate overall upgrading of asphalt mixing equipment, promote green logistics of asphalt concrete and encourage the use of low-emission warm-mix asphalt to replace traditional hot mix methods, which is prone to more VOCs emissions. At the same time, the city promotes the upgrade of pollution control facilities and advanced treatment technologies at the pilot sites, aiming to treat VOCs more efficiently. These actions reflect Beijing's broader shift toward source-specific, process-oriented VOCs control.

Technical Guide for Green Evaluation of Asphalt Mixture in Beijing (BJJT/ 0066-2022)

Source | Beijing Municipal Commission of Transport

Technical Requirement and Evaluation for Green Production of Asphalt Mixing Plants (DB11/T 2424-2025)

Source | Beijing Municipal Administration for Market Regulation

3) Domestic Sources

In addition to industrial and transportation-related sources, Beijing has also been focusing on VOCs emissions from everyday urban activities, particularly from catering and automotive repair.

Catering Industry

As a densely populated city with strong food services, cooking fume emissions from restaurants, street food stalls, and commercial kitchens have become a major component of total urban VOCs. The catering industry in Beijing is large, diverse, and often concentrated in mixed-use residential and commercial areas. Many small and medium-sized establishments operate with limited space and ventilation infrastructure, making the control of VOCs a significant challenge. Given this context in 2018, Beijing released the **Emission Standards of Air Pollutants for Catering Industry (DB11/1488-2018)**. Based on the national standard GB18483, this standard incorporates Beijing's unique requirements for air pollution management. It includes particulate matter and VOCs to the control list, targeting integrated removal of these two types of air pollutants. This is one of the first local standards in China to set clear limits on non-methane VOCs emissions for the catering industry, providing quantitative indicators for VOCs control.

Emission Standards of Air Pollutants for Catering Industry (DB11/1488-2018)

Source | Beijing Municipal Ecology and Environment Bureau

To facilitate the implementation of the standard, specific operational requirements are also outlined to provide

scientific guidance for the selection of purification facilities in the catering industry, with economically reasonable maintenance and inspection requirements clearly defined. In addition, Beijing actively provides guidance and assistance to catering establishments in the processes of planning, construction, restaurant site selection, leasing, registration, renovation, pre-opening and so on, improving the environmental management level of the catering sector.

Automotive Repair Industry

Among domestic VOCs sources, the automotive repair sector in Beijing represents another significant contributor due to its widespread use of solvent-based coatings and auxiliary materials. By the end of 2023, there are 4,890 registered auto repair businesses in the city. Emissions inventories over the past five years show that the auto repair industry in Beijing emits approximately 2,000 tons of VOCs annually, accounting for 3.3% of domestic sources. Therefore, this area requires high attention in Beijing's domestic pollution prevention and control efforts.

In response, the city has developed a series of specialized local standards, including the **Emission Standard of Air Pollutants for Vehicle Maintenance and Repair Industry (DB11 1228-2025), Technical Guidelines for Environmental Impact Assessment - Vehicle Maintenance Industry and Repair Industry (DB11/T 2058-2022), Technical Specifications for Pollution Prevention and Control of Vehicle Maintenance and Repair Industry (DB11/T 1426-2017), and Assessment Indicator System of Cleaner Production for Motor Vehicle Repair and Dismantling (DB11/T 1265-2015)**. These standards regulate emission limits, VOCs content in raw materials, purification equipment requirements, and

Emission Standard of Air Pollutants for Vehicle Maintenance and Repair Industry (DB11 1228-2025)

Technical Guidelines for Environmental Impact Assessment - Vehicle Maintenance Industry and Repair Industry (DB11/T 2058-2022)

Technical Specifications for Pollution Prevention and Control of Vehicle Maintenance and Repair Industry (DB11/T 1426-2017)

Assessment Indicator System of Cleaner Production for Motor Vehicle Repair and Dismantling (DB11/T 1265-2015)

Source | Beijing Municipal Ecology and Environment Bureau, Beijing Municipal Administration for Market Regulation, and Beijing Municipal Administration of Quality and Technology Supervision

operational practices like record keeping. The government has also published the **Beijing Municipal Handbook on Pollution Prevention and Control in the Automobile Repair Industry** and **Technical Guidelines for On-Site Inspection**, providing guidance to operators and officers for on-site enforcement and inspection. In addition to setting rules, Beijing applies graded supervision and performance-based regulation. The **Implementation Rules for the Assessment of Pollution Prevention Performance Ratings in the Motor Vehicle Maintenance Industry of Beijing (Trial)** was developed to support the identification of green enterprises and the emergency emission reduction enterprise list during heavy-air-pollution warning days. Lastly, innovative technologies are adopted to ensure accurate enforcement and data-driven actions. Mobile VOCs monitoring vehicles, infrared sensors, and power usage analytics are applied to identify pollution hotspots, trace sources, and verify the synchrony of pollution control equipment with actual production activity.

Furthermore, the city also promotes the replacement of raw and auxiliary materials with low (or zero) VOCs content in both public and private sectors with various measures. In 2018, the **Beijing Action Plan for Important Measures to Deepen Reform and Expand Opening Up** limited VOCs-containing materials that are used in building coatings and controlled organic solvent pollution at the source. Following the green procurement policy updated in September 2018, new construction projects and maintenance projects using public funds must apply low-VOCs-content coating materials and adhesives, starting in 2019.

Additionally, strictly enforcing VOCs content limit standards is implemented by conducting random inspections across different stakeholders, such as supermarkets, building material markets, and manufacturing enterprises. The government regularly exposes on its website products that fail to meet standards along with their manufacturers and sales locations. For products with two or more batches failing inspections, manufacturers are legally traceable and held accountable. Besides, for those industrial enterprises with high annual VOCs emissions (1 ton or more), the government encourages them to conduct clean production assessments and simultaneously address VOCs-related issues identified during the assessment.

Architectural Industry

Apart from the measures above, Beijing has established standards to set clear limits on the VOCs content of architectural coatings and adhesive products to reduce VOCs emissions. Unlike traditional industrial sources that can employ end-of-pipe treatment facilities for VOCs reduction, the application of architectural coatings and adhesives typically occurs in open spaces, generating fugitive emissions that can hardly be captured or treated. Reportedly, the VOCs emissions generated

from architectural coatings and adhesives, particularly with the usage of solvent-based products, exceed 8,000 tons per year.

To align with national standards, address Beijing's VOCs reduction requirements, protect the environment, and safeguard public health, the **Beijing Municipal Standard for Volatile Organic Compound Content Limits in Architectural Coatings and Adhesives** refines VOCs content limits for these products. This initiative promotes the development and adoption of low-VOCs products within the architectural coatings and adhesives manufacturing sector, thereby reducing VOCs emissions during their application. **Limit Standards of Volatile Organic Compounds of Architectural Coatings and Adhesives** (DB11/ 1983-2022) has been revised based on DB11/3005-2017 to align with national standards and meet the evolving requirements of Beijing's goal on VOCs reduction.

This limit standard further refines VOCs content limits for architectural coatings and adhesives, thereby reducing VOCs emissions during the use of these products. The establishment also promotes the development and application of low-VOCs products within the manufacturing industry.

By introducing enforceable emission standards across sectors and strengthening both supervision and support, Beijing is gradually transforming all these sectors into more regulated ones and providing best practices for other cities pursuing low-VOCs urban development strategies.

Limit Standards of Volatile Organic Compounds of Architectural Coatings and Adhesives (DB11/ 1983-2022)

Source | Beijing Municipal Ecology and Environment Bureau

3. Case Study:
Mobile Monitoring of VOCs in Auto Repair Parks

3.1 Background and Objectives

In Beijing, the auto repair and spray-painting sector is a substantial VOCs emission source, particularly in clustered auto repair parks located in urban and suburban areas. The three major processes leading to significant VOCs emissions include vehicle maintenance and repair, painting, and the storage of hazardous waste. First, during vehicle maintenance and repair activities, VOCs are emitted when vehicle parts are cleaned using organic solvents. Second, the painting process, which involves steps such as paint mixing, spraying, drying, and cleaning, is reported as the primary source of VOCs emissions in the auto repair industry. Last, VOCs emissions can occur during the hazardous waste storage process if the sealing is inadequate. Given the multiple emission points and operational steps involved, VOCs management in the auto repair industry remains particularly complex and challenging. In addition, auto repair parks often house dozens to hundreds of small workshops, many of which operate with limited environmental controls, making emissions diffuse, complex, and difficult to supervise through traditional means.

Traditional offline monitoring methods involve periodic manual sampling using various external monitoring instruments, followed by analysis of the collected samples in a laboratory. Offline monitoring analysis offers advantages such as high accuracy and sensitivity of analytical results. However, the analysis process is time-consuming and labor-intensive, with stringent requirements for the operating environment, and restricts the monitoring of real-time changes in VOCs concentrations in a given area.

Manual Sampling for Traditional Offline VOCs Monitoring

Source | Beijing Municipal Research Institute of Eco-Environment Protection

To address this challenge, as a complement to traditional VOCs monitoring methods, Beijing has actively explored and adopted mobile monitoring to strengthen real-time, spatial resolution supervision of VOCs emissions from the auto repair parks. The goal is to transition from passive, periodic enforcement to proactive, data-driven environmental management.

Mobile monitoring of VOCs mainly uses mass spectrometry methods. Compared with sensor and optical methods, mass spectrometry features accurate response, high sensitivity, and strong interference resistance. Meanwhile, its data resolution

is comparatively higher than that of chromatography. The specific technical routes are divided into soft ionization and hard ionization routes. However, each technical route has its own limitations and shortcomings, and there is an urgent need for standardized guidelines and regulatory frameworks to address these issues.

The updated technical specifications for mobile monitoring of VOCs should standardize various aspects, including instrument performance parameters, quality assurance and control, and evaluation analysis, to achieve a standardized mobile monitoring system. This will enhance the comparability and applicability of data, thereby providing a solid foundation for precise VOCs control in Beijing.

3.2 Implementation

In the past five years, Beijing has organized multiple rounds of municipal-level targeted enforcement campaigns, focusing on VOCs emissions from the auto repair industry and other sources. Mobile monitoring can directly obtain the specific concentration of each VOC substance, and categorizes VOCs concentrations into seven levels. The lowest level, with concentrations ranging from 0 to 200 μg/m^3, is displayed in green on real-time maps. The highest level, with concentrations exceeding 1,200 μg/m^3, is indicated in purple. From the lowest to the highest level, the color progresses from green, light yellow, yellow, orange, red, pink, to purple. This color-coded concentration display method facilitates monitoring agencies in mapping VOCs concentration and identifying areas with high pollutant concentrations.

For example, in the Laiguangyingxiang township of Chaoyang District, 28 auto repair businesses have gathered here, forming a relatively large auto repair cluster. In 2023, according to mobile monitoring results, the Laiguangyingxiang auto repair cluster area had an average of one high-value point every 2.6 km, with peak concentrations reaching several thousand μg/m^3, significantly impacting the daily lives of surrounding residents. Accordingly, multiple monitoring points in this area are marked as red bubbles on the map. After identifying key areas with high VOCs emissions using mobile monitoring, other measures are implemented to pinpoint auto repair companies, such as using the micro-scale atmospheric pollutant dispersion model. For companies identified, the government employs a combination of infrared remote sensing, electricity consumption monitoring, portable monitoring devices, and other investigative tools to conduct thorough on-site assessments. These methods enable inspectors to find out unreported operations, malfunctioning VOCs control systems, and other irregularities. Based on these diagnostics, the government develops tailored “one-enterprise-one-policy” action plans for each non-compliant enterprise, providing professional technical guidance.

Pollution Distribution Map that was generated based on data provided through VOCs mobile monitoring

Source | Beijing Municipal Ecology and Environment Bureau

VOCs Mobile Monitoring

Source | Beijing Daily Group

▪ **Main Working Progress to Develop the Technical Specifications for Mobile Monitoring and Evaluation of Volatile Organic Compounds**

2022	March	• Initiated the development of the technical specifications and established a working group.
	April to July	• Reviewed domestic and international standards and literature, assessed the current state of mobile VOCs monitoring technologies in China, and established the technical route and structure of the specifications.
	August to September	• Conducted field research on existing manufacturers of vehicle-mounted VOCs monitoring instruments, performed technical testing, identified key monitoring parameters, and evaluated differences in instrument performance while developing quality assurance and control protocols.
	October to December	• Drafted the initial version of the specifications, refined the content under the guidance of the Monitoring Division of Beijing Municipal Ecology and Environment Bureau, and conducted data analysis and experimental validation.
2023	January 10 to 20	• Held internal expert consultation to gather professional feedback and finalized a draft for public comment based on feedback.
	April 27 to May 26	• Released draft specification released for public comments to finalize the specification.
	December 25	• Officially approved.

On the other hand, following the growing demand for standardized mobile monitoring in VOCs governance, Beijing Municipal Ecology and Environment Bureau initiated the development of the **Technical Specifications for Mobile Monitoring and Evaluation of Volatile Organic Compounds** in March 2022. This local standard **DB11/T 2174-2023** came into force on April 1, 2024, marking a significant step in standardizing high-resolution, data-driven VOCs supervision.

3.3 Outcomes

The mobile monitoring technology and the released standards have driven the refined management of VOCs pollution in the auto repair industry, resulting in a noticeable improvement in air quality in the areas surrounding auto repair clusters.

In addition to monitoring and analysing the collected data itself, Beijing has integrated the mobile data captured with existing emissions inventories, power usage records, and enterprise production schedules to identify unregulated activities. For example, if VOCs levels remain high at times when facilities report no activity, it may indicate unreported or illegal operations.

Taking the high-VOCs area in the Laiguangyingxiang township as an example, the authorities use mobile monitoring to visualize and identify high-VOCs hotspots for targeted on-site investigations and source tracing. Based on the results, they conducted an in-depth investigation, established 36 hotspot monitoring grids covering an area of 22 km^2, and defined a total of 6 categories and over 40 typical pollution issues in the auto repair industry, including problems from paint mixing, spray painting, pollution control facilities, and hazardous waste management.

Through refined control of VOCs emissions, upgrading and enhancing the efficiency of treatment facilities, and strengthening the standardized management of hazardous waste, as of October 2024, the number of high-value red-bubbles in the North Fifth Ring Road auto repair cluster has significantly decreased, along with a lower frequency of occurrence. The number of high-value points that is detected per mobile monitoring session has reduced from an average of three to one, with a peak concentration reduction exceeding 80%. Residents have also reported that unpleasant odors are now rarely noticed when passing by.

Vehicle-mounted Mobile Monitoring

Source | Beijing Municipal Ecology and Environment Bureau

4. Reflections and Recommendations

Beijing's VOCs governance offers several valuable lessons for other megacities which are experiencing a similar urban transition.

1) Develop Stricter Local Standards Based on the City's Own Capacity

Building upon the foundational framework of national regulations and standards, Beijing has consistently advanced its VOCs governance by establishing more stringent local instruments. The city leverages its strong institutional and technical capacity, effectively raising the threshold for compliance while keeping the requirements technically attainable.

2) Adopt a Phase-based, Source-targeted Approach

An effective approach to VOCs reduction and management involves a phased and source-targeted deployment of resources. Beijing has initially focused on regulatory stringency on sectors with the highest emission impact, such as fuel distribution, printing, and industrial coating. Following the successful mitigation in these key areas, measures have been gradually extended to cover more complex, dispersed emission sources like catering, auto repair, and small-scale manufacturing.

3) Invest in Technical Capacity-building for Precision Enforcement

Equipped with advanced technologies, regular inspections can enable more effective targeted enforcement of stricter local standards. Vehicle-mounted VOCs monitoring serves as an example to show how technological applications can significantly improve enforcement. Authorities are able to track down the sources of pollution more effectively by mapping emissions hotspots in real time, especially within clusters of small businesses. Furthermore, when mobile monitoring data is integrated with other operational data, like energy consumption records, abnormal and underreported operations can be uncovered and identified. This increases the credibility and data-drivenness of compliance checks.

4) Promote Low-VOCs Products across Sectors and Strengthen Behavioral Change

Promoting the application of low-VOCs products in both public and private sectors is a practical and effective strategy to control the source of VOCs emissions. Measures such as mandating low-VOCs products application in public projects and promoting private sector adoption through certification and labeling, can reduce VOCs emissions from sources. In addition, regularly disclosing non-compliant products publicly and conducting random consumer goods inspections can significantly increase market pressure for compliance. Lastly, public involvement is essential for long-term VOCs reduction. Encouraging citizens to consume low-VOCs products can shape low-emission behavior and promote voluntary compliance.

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