발간등록번호
51-6110000-002710-14

Seoul-Beijing Bilateral Research Report 2022

A Comparative Study of Climate Policies in Seoul and Beijing

SEOUL METROPOLITAN GOVERNMENT

Seoul-Beijing Bilateral Research Report 2022

A Comparative Study of Climate Policies in Seoul and Beijing

Letter of Submission

Dear mayor of Seoul,

I hereby submit this report as the final draft of "Seoul-Beijing Bilateral Research Report (2nd)".

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Executive Summary

In recent decades, the Republic of Korea and China experienced tremendous economic development that came at an environmental cost, putting pressure on long-term economic and social sustainability. While the national governments lay out ambitious climate blueprints, both Seoul and Beijing affirmed their carbon neutrality goals by 2050 and no later than 2060 and contributed to the targets set in the Paris Agreement. Against this background, the capitals play an indispensable role in demonstrating innovative policies, technological innovation, financial mechanisms, and decarbonization strategies to enable an economy-wide transition. As frontrunners in their respective countries, both metropolises are testbeds for innovation with successful best practices for knowledge exchange, technological innovation, and international cooperation.

Even before the carbon neutrality commitment, Seoul and Beijing have high environmental awareness due to urbanization and population pressures. Therefore, the cities have been putting concerted efforts and experimenting with different solutions in addressing climate change and air pollution issues. The cities established strong institutions and effective climate governance structures to lead and coordinate climate issues to enable change. The second Seoul-Beijing bilateral report aims to present both cities' experience in climate strategies, institutional governance, and low-emission actions in the energy, building, and transport sectors, as the foundation for both cities' annual bilateral exchange, achievements, and valuable lessons for global cities interested in targeting carbon neutrality.

Climate policies

Seoul has a long history in climate change policies and interventions due to its strong awareness and commitment. In 2006, Seoul joined the C40 Cities Climate Leadership, and in 2009, Seoul hosted the C40 World City Climate Summit and adopted the Seoul Declaration to embody integrated solutions to tackle the climate crisis. In addition, Seoul adopted the *Seoul Metropolitan Government (SMG) Ordinance on Tackling Climate Change* in January 2009, and it has been consistently putting in the effort to respond to climate change since 2015. Recently, the *2050 GHG Emission Reduction Strategic Plan* and the *2050 Seoul Climate Action Plan* also showed the long-term strategy to meet the carbon neutrality goal by 2050. Furthermore, in January 2022, Seoul established the Five-Year Climate Change Action Plan (2022-2026).

Beijing develops *Five-Year Plans (FYP)* to guide the city's climate action. In 2016, Beijing published the *13th FYP for Energy Conservation and Climate Change,* highlighting key climate actions from 2016 to 2020. The plan incorporated critical climate-related systems and sectors. Meanwhile, Beijing designed specific sectoral FYPs, including the energy, building, and transport sectors. The climate change FYP and sectoral FYPs create a comprehensive policy framework to guide sustainable development. In 2021, the first year of the 14th Five-Year Plan period, Beijing is developing the *14th FYP for climate change* and a *carbon neutrality roadmap*.

Climate governance

Seoul's *Climate and Environment Headquarters ("Headquarters")* develops and implements climate strategies in a comprehensive and well-organized manner. Under the Headquarters' leadership, Seoul adopts a multi-dimensional approach to establish carbon neutrality and a resilient city. Eight divisions under the headquarters formulate plans and policies tailored to thematic areas, such as climate change, air quality, and green energy. As the capital, Seoul also actively leverages partnerships with the National Assembly, City Council, and affiliated research agencies to maximize the effectiveness and efficiency of local climate actions. In addition, to support the discovery of new policies and reviews of critical sectors, such as building, transport, waste, the Climate Crisis T/F (task force) has also been constituted during the establishment of the *2050 Seoul Climate Action plan*. The Climate and Environment Headquarters is responsible for considering and deciding the implementation of central climate policies. The Seoul Institute, a prominent think tank of the city, lays the groundwork for establishing and implementing policies.

Under the Ecological Conservation Commission, the *Comprehensive Air Pollution Control and Climate Change*

Response Working Group in Beijing is the top-level decision-making group coordinating different bureaus and designing comprehensive climate policies. The *Beijing Municipal Bureau of Ecology and Environment (BEE)* is the agency that handles climate policy planning. Similar to Seoul, BEE integrates climate and environment policies to maximize co-benefits. In addition, BEE manages a research institute, *Beijing Climate Change Management Center,* to provide knowledge support for climate governance.

Climate change adaptation

Every five years, Seoul establishes a detailed plan for climate change adaptation measures based on the *Ordinance on Low Carbon, Green Growth for the City of Seoul*. SMG is also developing a *Seoul Climate Change Adaptation Action Plan*, including GHG reduction policies and climate change adaptation measures. Over the past five years, through the *Seoul Climate Change Adaptation Action Plan (2017-2021)*, Seoul controlled four major sectors: health (heat wave, infectious disease, and air pollution); disaster risk management; water management; and forest and ecosystem health. Recently, the *Seoul Climate Change Adaptation Action Plan (2022-2026)* has been established, and the plan includes 66 projects in four major areas, such as water management, ecosystem, facility management, and health.

Witnessing the negative impacts caused by climate change, Beijing releases policies to adapt to climate change. The city builds resilience to climate change by focusing on three key areas: *urban infrastructure development, resilience management system,* and *extreme weather management*. To cope with floods, the heat island effect, and other threats, the city updated urban planning standards and implemented several key infrastructure projects, such as the Sponge City and the Urban Ventilation Corridors. Beijing strengthens the resilience management system by increasing risk prediction, monitoring and control capabilities. The city also solidified extreme weather management by issuing new regulations, building capacity, and protecting vulnerable groups.

Air quality management

Seoul considers local conditions and develops the Action Plan for Metropolitan Air Quality Control (2015-2024) based on the Second Metropolitan Air Quality Control Basic Plan. In order to implement this, Seoul has set specific measures for its main emission sectors. The $PM_{2.5}$ concentration level of Seoul is mainly caused by transport (44%), heating (31%), and fugitive dust (22%). The transportation sector's measures include supporting low-pollution projects for old vehicles and construction machines, limiting vehicle use, and expanding the supply of low-pollution vehicles, such as EV and hydrogen vehicles, by increasing charging stations. In the heating sector, general boilers are converted into eco-friendly boilers, and large-scale emission plants are regulated on the total air pollutants emissions. In small businesses, fees are provided to support the installment of air pollutant prevention. In addition, SMG maintains environmentally-friendly construction sites and strengthens road cleaning to manage fugitive dust. In addition to daily measures, Seoul further adopts seasonal control measures from December to March to enhance sectoral actions for improving air quality.

Beijing develops mid- and long-term plans aligning with the national agenda for environmental protection, such as Five-Year Plans for Environmental Protection and Clean Air Action Plan as mid- and long-term goals and annual plans for improving air quality. Beijing expanded financial support to air quality management from 2013 and promoted the coal-to-gas and coal-to-electricity transition applied to coal-fired boilers for industrial use. In terms of transport emissions control, Beijing facilitates two transformations: road-to-train; and fossil fuel-to-electricity. Beijing strengthens real-time monitoring of construction sites with GPS satellite technology and imposes a punishment. Furthermore, Beijing adopts seasonal control actions combined with regional coordination policies developed by the national government.

Low-carbon actions

Clean energy

Seoul implements various policies to promote sustainable energy transition. With the vision to increase energy independence, the city focuses on *expanding renewable energy* and *improving energy efficiency*. Seoul has laid a solid foundation from administrative, regulative, and financial perspectives in terms of renewable energy expansion. Considering the urban conditions and challenges, Seoul has been active in expanding solar energy and implemented two phases of the *One Less Nuclear Power Plant* and the *Solar City, Seoul*, and supplied solar power and hydrogen fuel cell under its *2050 GHG Emissions Reduction Strategic Plan* Moreover, in terms of energy efficiency improvement, Seoul promoted several strategies, including community energy, Green Data Center with the application of green IT and virtual server, installation of eco-friendly equipment, and smart energy management systems with the engagement of the private sector. Since public engagement is key to the sustainable energy transition in the urban context, Seoul highly encourages the public to play an active role as *energy prosumers*, a dual-function of energy producer and consumer.

Beijing's energy sector development contributed significantly to improving energy efficiency and air quality in the city. Beijing almost eliminated the use of coal through the coal-to-clean energy transition. The government invested in planning and building new gas and power infrastructure. Regional cooperation in importing power, especially power generated by renewable energy, plays a vital role in the coal-to-clean energy transition. Beijing has quickly improved renewable energy to 10.4% in the energy mix by 2020. The increase in renewable energy was attributed to government-invested pilot projects and subsidies. For example, the Six Sunshine Project identified priority areas, provided subsidies, and promoted public engagement for solar energy development. On the energy consumption end, Beijing strengthens energy consumption monitoring to improve the energy efficiency of large energy consumers.

Low-carbon buildings

Seoul has invested different resources into greening the building sector, the largest energy consumer and GHG emitter, resulting in 68.8% of Seoul's total GHG emissions in 2018. Therefore, greening the building sector is the core to the Seoul climate policy. Seoul devises strategies for green buildings tailored to various building types while encouraging the public sector to take the lead in decarbonizing the building sector. Firstly, Seoul launched the *Green Remodeling Program* for old public buildings and the *Building Retrofit Project* for old private buildings. Seoul provides financial incentives to foster private sector engagement. Secondly, Seoul introduced the *Zero Energy Building (ZEB)* initiative to guide new building development. To promote ZEBs, Seoul implemented an R&D demonstration project, launched a ZEB development roadmap, and provided financial incentives to private stakeholders. Finally, Seoul implemented the *GHG emission cap scheme* for buildings. The initial application focused on public-owned buildings and eventually expanded to private ones. Similar to the emission cap scheme, Seoul operates a building efficiency certification program to monitor the energy efficiency performance of buildings better.

Beijing has adopted various policies to promote the low-carbon transition of the building sector. Firstly, Beijing promotes *old building renovation*, especially public buildings. A core element in the renovation program is the energy system within buildings, such as heat networks and power grids. Secondly, Beijing launched several low-carbon building programs, including *green buildings* and *prefabricated buildings*. To promote green building development, Beijing released guidance, implements government-funded pilots, and provides subsidies. As of 2019, 402 building projects of 45.9 million square meters are certified as green buildings, and 93% of green building areas are certified as two stars or above. Thirdly, Beijing has been implementing the energy consumption monitoring and quota mechanism to target large public buildings with massive energy consumption. From 2014 to 2018, the public building energy consumption monitoring system avoided 1.97 billion kWh of electricity consumption. Beijing also regularly updates *building energy efficiency*

standards to foster the development of energy-efficient buildings.

Transport

Transport is the second-highest energy consumer and GHG emitter after the building sector in Seoul, emitting 19.2% of Seoul's GHG emissions in 2019. It is also a critical sector for air pollution management control. Guided by the *Seoul Transport Vision 2030*, which envisions a *"Livable Seoul - without relying on cars"*, the city's transport decarbonization strategy is anchored on three main pillars: *human; sharing;* and *environment* that prioritizes accessibility over vehicular movement by providing multimodal mobility services to reduce energy consumption and emissions. In addition, since the announcement of Korea's Green New Deal, there has been a renewed focus to accelerate electric vehicle deployment by announcing the most ambitious electric vehicle plan in 2021 and integrating renewable energy transition in transport. While Seoul's efforts have significantly increased the use of public transportation (65%), more can be done on reducing fossil-based energy (89%) and growing city gas (7%), electric (3%), and renewable energy use (1%) in the transport sector.

The *Beijing Transport Development Plan 2004 - 2020* has guided the city's transport development through the annual Comprehensive Transport Action Plans. Beijing has strengthened Transit-Oriented Development (TOD) and Transport Demand Management (TDM) to integrate urban and transport planning. As a result, green mobility trips have increased significantly to 74.1% in the city center, while automobile ownership decreased dramatically to an annual growth rate of 4.6% in 2020 from 19.7% in 2010. Besides that, Beijing also adopts innovative technology means and encourages behavioral change through the carbon credit accounting and trading system hosted on the Beijing Mobility-as-a-Service (MaaS) platform. Finally, the city also works closely with the central government to electrify transport to achieve carbon neutrality and clean air.

Recommendations

Seoul and Beijing have adopted multiple climate strategies, institutional arrangements, and sectoral policies to achieve low-carbon development. These policies formulate a basis for the two cities to cut GHG emissions. However, Seoul and Beijing need to strengthen current actions further and apply innovative policies to meet challenges to achieve carbon neutrality. The two cities face similar policy and technology challenges, such as reliance on fossil fuels and numerous old buildings. Strengthening city-to-city cooperation between Seoul and Beijing helps the two cities explore, design, and implement policies to achieve carbon neutrality. Based on the current policies and challenges analysis, the project team recommends the following actions to strengthen their cooperation. Design integrated climate solutions

- *Design integrated climate solutions*
- *Conduct joint research on MRV systems for climate strategies and projects*
- *Organize exchanges to promote coordination and collaboration with stakeholders*
- *Explore cooperation opportunities on climate finance-related and market-oriented actions, such as climate budget and carbon tax*
- *Conduct joint research on demand-side management*
- *Establish working groups on technical innovation and promotion*

Acronyms and Abbreviations

℃	Degree Celsius
%	Percent
μg	Microgram
AR5	IPCC's Fifth Assessment Report
BAU	Business as usual
BEE	Beijing Municipal Bureau of Ecology and Environment
BEMS	Building Energy Management Systems
BIPV	Building-integrated photovoltaics (BIPV)
BMBEIT	Beijing Municipal Bureau of Economy and Information Technology
BMCDR	Beijing Municipal Commission of Development and Reform
BMCHURD	Beijing Municipal Commission of Housing and Urban-Rural Development
BMCPNR	Beijing Municipal Commission of Planning and Natural Resources
BMCT	Beijing Municipal Commission of Transport
BRT	Bus Rapid Transit
CCUS	carbon capture, utilization and storage
CDM	Clean Development Mechanism
CH_4	Methane
CNG	Compressed natural gas
CNY	Chinese Yuan (Chinese currency)
CO	Carbon monoxide
CO_2	Carbon dioxide
CPU	Central Processing Unit
FYP	Five-Year Plan
GDP	Gross domestic product
GFA	Gross Floor Area
GTZ	Green Transportation Zones
GW	Gigawatts
HFC_S	Hydrofluorocarbons
kW	Kilowatt
ITMO	Internationally Transferred Mitigation Outcomes
IPCC	the Intergovernmental Panel on Climate Change
LEZ	Low Emission Zones
LNG	Liquefied natural gas
LPG	Liquified petroleum gas
LULUCF	Land use, land-use change and forestry
m	Meters
m^2	Square meters
m^3	Cubic meters

MaaS	Mobility-as-a-Service
MEE	Ministry of Ecology and Environment of the People's Republic of China
mm	Millimeter
MOHURD	Ministry of Housing and Urban-Rural Development of the People's Republic of China
MoLIT	Ministry of Land, Infrastructure, and Transport of Republic of Korea
MoU	Memorandum of Understanding
MRV	Monitoring, Reporting and Verification
Mt	Million tones
MW	Megawatts
NbS	Nature-based Solution
NDC	Nationally Determined Contributions
NDRC	National Development and Reform Commission
N_2O	Nitrous oxide
NO_2	Nitrogen dioxide
NO_X	Nitrogen oxides
ODA	Official Development Assistance
O_3	Ozone
PFC_S	Perfluorocarbons
$PM_{2.5}$	Particle matter with aerodynamic diameter of 2.5μm or less
PM_{10}	Particle matter with aerodynamic diameter of 10μm or less
PV	Photovoltaic
R&D	Research and development
RCP	Representative Concentration Pathway
RPS	Renewable Portfolio Standard
SF_6	Sulfur hexafluoride
SMG	Seoul Metropolitan Government
SO_2	Sulfur oxide
TDM	Transport Demand Management
THUBERC	Tsinghua University Building Efficiency Research Center
tce	Tons of coal equivalent
toe	Tons of oil equivalent
UNEP	United Nations Environment Program
VESTAP	Vulnerability Assessment Tool to Build Climate Change Adaptation Plan
VKT	Vehicle-kilometers Travelled
VOC_S	Volatile organic compounds
VSC-HVDC	the Voltage Source Converter-High Voltage Direct Current

Chapter 1.

Project Introduction

Human-induced climate change has been affecting many regions and seasons across the globe, as it reached approximately 1 degree Celsius (°C) above pre-industrial levels in 2017, with trends showing that it will increase at 0.2 °C per decade (IPCC, 2021). At the same time, the world is still far from meeting the Paris Agreement goals of limiting global warming to 1.5 °C. The recent UN Climate Change Conference of the Parties (COP26) climate deal at Glasgow suggests that current policies will lead the world between 1.8 and 2.4 °C of warming. To avoid the catastrophic consequences of climate change, the world must take swift and solid action to drastically reduce global greenhouse gas (GHG) emissions (IPCC, 2021).

Cities play an essential role in tackling climate change. Cities account for more than 50% of the global population, 80% of the worldwide GDP, two-thirds of the global energy consumption, and more than 70% of the annual global CO2 emissions. Moreover, these factors are expected to grow significantly, as over 70% of the worldwide population is anticipated to live in cities by 2050, leading to huge energy demand. Therefore, cities are the central platform to improve people's livelihood while ensuring a net-zero future.

1.1 History of climate cooperation between Seoul and Beijing

In honor of the twentieth anniversary as sister cities, the Seoul Metropolitan Government (Seoul or SMG) and the People's Government of Beijing Municipality (Beijing) established the "the Joint Committee of Exchanges and Cooperation" in 2013 for more systematic and pragmatic cooperation between the two cities. The Joint Committee of Exchanges and Cooperation puts the two mayors as honorary committee chairs, incorporating three teams: the Economy, Cultural, and Education. In 2015, the two cities agreed to increase the establishment of the Environmental Team to strengthen air quality and sustainable development. Each city rotates in hosting a biennial forum to review the progress and decide collaborative actions for the next two years.

The environmental theme is one of the core parts of the Seoul-Beijing Joint Committee cooperation framework, especially in air pollution and climate change. With the mechanism and actions of the environmental team, the two cities have actively shared policies and achievements and peer-to-peer learning. In 2018, Seoul and Beijing agreed to establish Seoul-Beijing Air Quality Management Joint Study Institute to share the achievements in environmental science and technology research and further increase bilateral exchanges in the air quality management field.

In July 2019, the two sides agreed on joint research projects, and as a short-term task, they decided to work on a joint study report to share the excellent policies tackling climate change.

In 2019, ICLEI East Asia supported the first round of the Seoul-Beijing Bilateral Cooperation Research Project focusing on air quality management. The project analyzed the progress and challenges faced by the two capitals on air pollution, one of the most severe environmental threats in both cities. In addition, the project report analyzed the two cities' air quality management policies in priority areas, including boiler renovation, transportation, and fugitive dust management.

The cooperation is more relevant, as both the Republic of Korea (Korea) and China announced ambitious carbon neutrality goals by 2050 and 2060, respectively. Therefore, the second round of the Seoul-Beijing Bilateral Cooperation Project seeks to analyze and advise climate policies.

1.2 Research objective

The fundamental objective of the research project is to support the two capitals' ambition on carbon neutrality. Realizing Korea's and China's carbon neutrality targets requires concrete actions at the local level. As capitals, both cities are considered trendsetters for other cities as they possess strong economic, technical, and scientific advantages to achieve carbon neutrality. However, carbon neutrality is an emerging task involving multiple

sectors (e.g., energy, industry, and building) and complex processes (e.g., policy plan, implementation, and evaluation), which pose challenges for cities. This project aims to support the two cities in meeting these challenges by summarizing released policies and providing tailored cooperation recommendations.

1.3 Research scope

The report primarily focuses on the climate policies issued at Seoul and Beijing municipalities. This report also includes critical climate policies released by both national governments, considering the significance of national policies on cities. A vital perspective of this report is also co-controlling or synergistic management of carbon emissions and air pollutants, as both national governments often emphasize this strategy as Seoul and Beijing battle climate and air pollution issues.

Both cities have a strong record of adopting climate environment policies. As elaborated in the Air Quality Research report, Seoul and Beijing started enhancing the energy sector in the 1960s. To provide up-to-date air quality management and climate change mitigation policies, this report mainly includes policies released after 2010. This report also deep dives into three sectors with significant climate impact - energy, transportation, and building.

Following this chapter, Chapter 2 introduces the climate and environmental landscape of the two cities. Then, chapter 3 explains the critical climate strategies and the overall institutional arrangement, while Chapter 4 elaborates sectoral low emission actions, including air quality management, energy, building, and transport. Finally, Chapter 5 provides recommendations for carbon neutrality via city-to-city cooperation based on the study findings.

1.4 Research methodology and limitations

The comparative study was done through data collection, analysis, and desk research, encompassing the summary and recommendations. Most of the primary data were collected through *Seoul's Climate and Environment Headquarters* and the *Beijing Municipal Bureau of Ecology and Environment.* In addition, the research team collected secondary data through official websites of both organizations, reports, and data that the government officially accepted. Although there have been limitations to reflect the latest data, the central policies, measures, and messages have been fully captured to fulfill the research purposes and cross-city comparison.

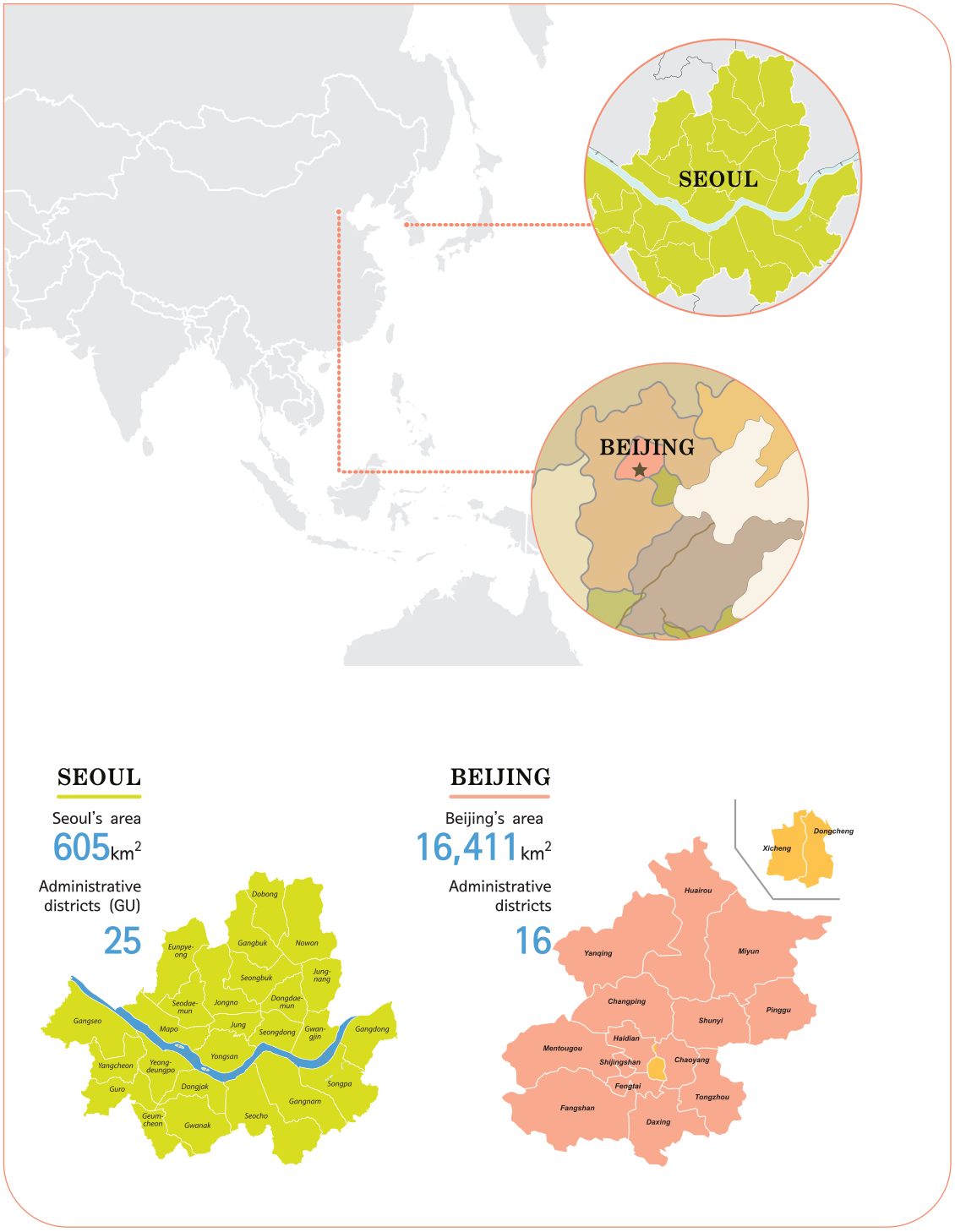
1.5 ICLEI Climate Neutrality Framework

ICLEI's definition of climate neutrality in the context of local and regional governments is *"the targeted reduction of GHG emissions and GHG avoidance in own operations and across the community in all sectors to an absolute net-zero emission level at the latest by 2050".* The aim is to pursue all efforts to limit the global temperature increase to 1.5 °C above the pre-industrial levels, in line with the Paris Agreement goals, which recognized the need for subnational governments to engage and act. ICLEI's approach highlights the need for **climate change adaptation** and enhances **climate resilience** across all sectors, in all systems and processes, aside from **climate mitigation**. Therefore, all governments need to set a clear goal to advance a holistic and integrated approach that leads to a myriad of co-benefits of sustainable development.

I Figure 1. ICLEI's Three pillars of climate neutrality

Chapter 2

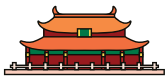
Background



I Map of Seoul (left, Climate and Environment Headquarters, 2021a) and Beijing (right, China Discovery)

CLIMATE AND ENVIRONMENT at a glance

Seoul



Beijing

Climatic conditions

	Seoul	Beijing
Annual mean temperature	12.8 °C (1991–2020)	13.8 °C (2019)
Average temperature change	11.83 °C (in the 1980s) to 12.88 °C (in the 2010s)	11.1 °C (1979) to 13.8 °C (2019)

Air Quality

	Seoul	Beijing
$PM_{2.5}$ (μg/m^3 in 2021)	19.8	33
Key policies	• Seoul Action Plan for the Second Metropolitan Air Quality Control • Seoul Air Quality Improvement Special Measures • Ten initiatives for air quality control • Eight initiatives for fine dust control	• Coal reduction • New energy vehicle promotion, new vehicle emission standard • Prefabricated building promotion, monitoring capacity improvement • Regional cooperation • Integrated management targeting VOCs

National Climate Strategies

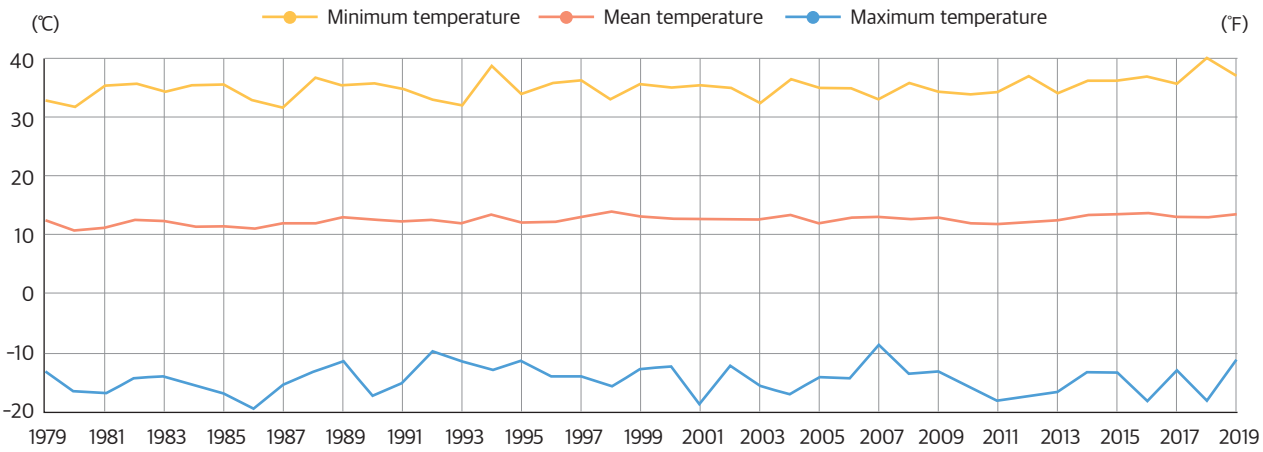
	Seoul	Beijing
GHG emissions	727.6 Mt CO_2eq (2018)	11,186 Mt CO_2eq (2014)
Targets	• 40% emission reduction by 2030 • Carbon neutrality by 2050	• Carbon peaking by 2030 • Carbon neutrality by 2060
Strategies	• The Framework Act on Low Carbon, Green Growth • The Third Five-Year Plan for Green Growth • Green New Deal	• Working Guidance for Carbon Dioxide Peaking and Carbon Neutrality in Full and Faithful Implementation of the New Development Philosophy • The Action Plan for Carbon Dioxide Peaking Before 2030 • 14th Five-Year Plan (FYP) for Economic and Social Development and Long-Range Objectives through to the Year 2035

Local climatic and environmental conditions are essential in understanding the rationale behind two cities' climate strategies. Air quality has received much public attention as Seoul and Beijing continue to experience significant air pollution days. Meanwhile, air quality management is closely related to climate change mitigation because many air pollutants and GHGs come from the same sources, such as fossil fuels and vehicles. This chapter also introduces national-level climate strategies, given their significant impact on local climate policies.

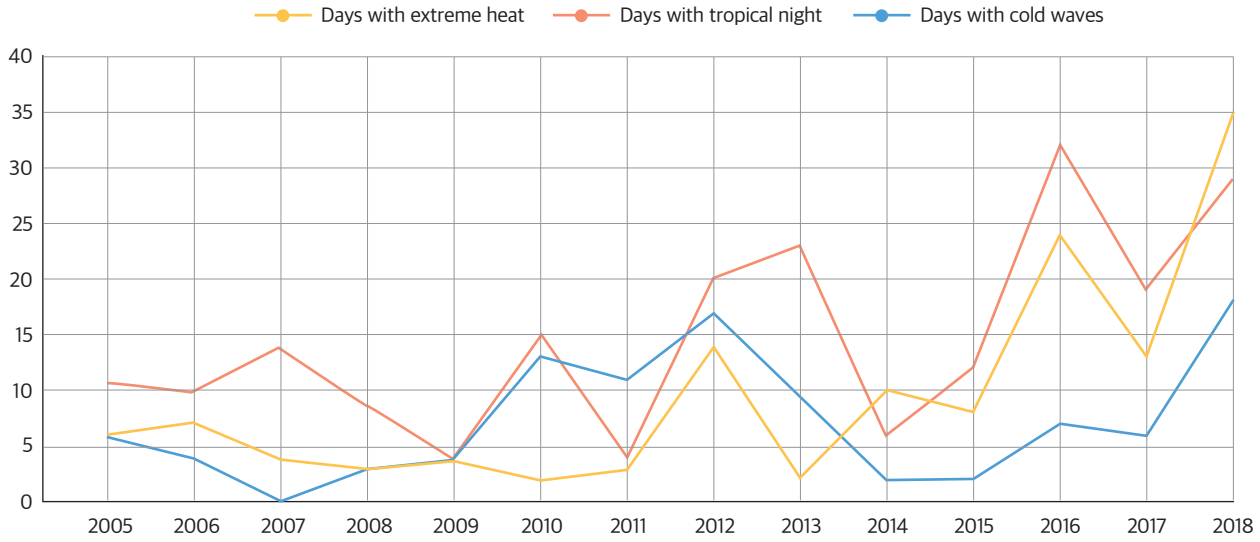
2.1 Local climatic and environmental conditions

2.1.1 Seoul

As the capital of Korea, Seoul is a large city hemmed in on four sides by mountains. The Han River, fed by several tributaries, meanders across the city and divides the city into the north and the south. The elevation increases from west to east. Due to the geophysical characteristic of the mountainous structure, long-range air pollutants transported by the western wind leads to severe seasonal air pollution as the mountains trap the air pollutants. In addition, topographic irregularities influenced the urban patterns; therefore, local and area-specific interventions are also introduced to overcome seasonal air pollution and climate change adaptation (Korea Methodological Administration, n.d.a).



I Figure 2. The trend of annual mean temperature in Seoul from 1979 to 2019 (Source: Korea Methodological Administration, n.d.b)



I Figure 3. The trend of extreme weather events in Seoul from 2005 to 2019 (Source: Climate and Environment Headquarters, 2021)

According to the National Institute of Meteorological Science, the annual mean temperature of Korea between 1912 and 2017 was 13.2 ℃. The mean yearly temperature increased at a rate of 0.18 ℃ every decade. It was also observed that the summer was 19 days longer than before, while the winter was 18 days shorter than before (Kim et al., 2018).

Seoul has a temperate climate (averaging at 12.8 ℃) with four very distinct seasons, resulting in drastic temperature differences in a year (averaging at 28.0 ℃). August is the hottest month with a mean temperature of 26.1 ℃, and January is the coldest (-1.9 ℃) (Korea Methodological Administration, n.d.a).

The yearly mean temperature trend from 1979 to 2019 (Figure 2) shows that Seoul's temperature has increased about one ℃ within 40 years (Korea Methodological Administration, n.d.b). Even with the one ℃ temperature increase, the impact can be felt with extreme heat in Seoul and abnormalities in the seasonal changes. The Seoul Institute study indicated that the ten-year average temperature during summer was 25 ℃ (between 2008 and 2017), 1.8℃ above the 1908 and 1917 periods. What is notable is the increased number of days with a daily maximum temperature over 25 ℃, from 122 days (between 2001 and 2010) to 136 days (in 2016) (H. Cho, 2017).

In the future, the rising trend of the city's annual mean temperature is expected to continue. When applying the methods and tools used in the IPCC's Fifth Assessment Report (AR5) to project Seoul's future climate, the annual mean temperature between 2091 to 2100 will be between 14.5℃ to 17.3℃ under different Representative Concentration Pathways (RCPs) (Table 1) (SMG, 2020a).

I Table 1. Projection of temperature change in Seoul (Data Source: Korea Meteorological Administration, 2017; SMG, 2020a)

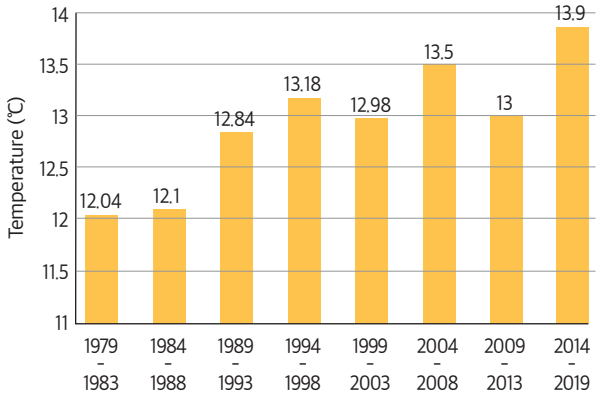
RCPs	A brief description of scenarios	CO_2 concentration in 2100 (Unit: ppm)	Annual mean temperature (℃)	
			2001-2010	2091-2100
RCP 2.6	A stringent mitigation scenario with the improved regenerative capabilities of the Earth	420	13.0	14.5
RCP 4.5	An intermediate scenario with the implementation of climate actions to a great extent	540		15.6
RCP 6.0	An intermediate scenario with the implementation of climate actions to some extent	670		16.0
RCP 8.5	No additional effort to constrain GHG emissions	940		17.3

2.1.2 Beijing

Located in the northern tip of the North China Plain, Beijing is surrounded by mountains along the west, the north, and the northwest, famously known as the Taihang Mountains and the Yan Mountain. The altitude differences between the west-east and north-south directions are significant, exceeding 1,000 m over short horizontal distances. The topography has an important influence on air pollution in downtown Beijing by producing anomalous southerly wind, high relative humidity, and sinking motion (Zhang et al., 2018).

The climate in Beijing belongs to the warm temperate zone, a half moist continental monsoon climate with four distinctive seasons. The annual average temperature is approximately 11 - 13 ℃ in plain areas. July is the hottest month, with an average temperature of 26 ℃ in plain areas. January is the coldest month of the year, and the average temperature is around -4 to -5 ℃. The spatial distribution of annual rainfall is uneven. The areas facing the windward slopes in the northeast and southwest have relatively stronger precipitation, where the annual rainfall is between 600 and 700 mm. On the contrary, the annual rainfall in the plains and some mountainous areas is between 500 and 600 mm. Around 75% of the annual rainfall occurs in the summer (Beijing weather, n.d.).

The temperature in Beijing has increased by 2.7 ℃ in the past 40 years. The annual temperature increased from 11.1 ℃ in 1979 to 13.8 ℃ in 2019, while the average between 1979 and 2019 was 13.0 ℃. During this period, the average temperature was 12.04 ℃ in 1979 and 1983, 0.96 ℃ lower than the 1979 and 2019 average temperature; while the average temperature in 2014 and 2019 was 13.82 ℃, 0.82 ℃ higher than the 1979-2019 average temperature (Figure 4). Similar to Seoul, Beijing witnesses a significant temperature rise.

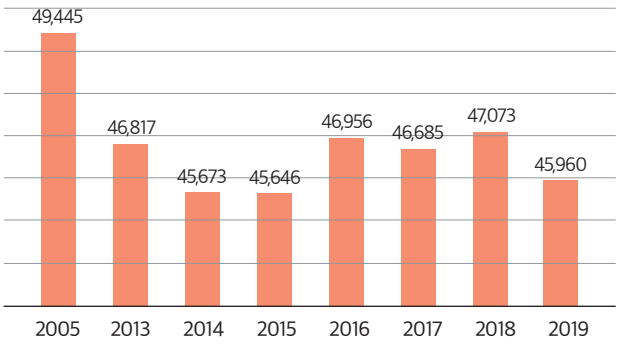


I Figure 4. The annual average temperature in Beijing from 1979 to 2019 (Data source: Beijing Statistical Yearbook, 2020)

2.2 GHG emissions of cities

2.2.1 Seoul

Seoul's total GHG emissions in 2019 were 45,960 $ktCO_2eq$, decreasing by 7.1% from the 2005 level. Energy is the dominant source for GHG emissions, accounting for around 91% of the total emissions, while waste and Industrial Processes and Product Use (IPPU) accounted for 6.41% and 3.2%, respectively. However, when taking a closer look at the energy sector, building and transport contribute to most GHG emissions from energy consumption, comprising 68.7% and 19.2%, respectively. Meanwhile, Agriculture, Forestry, and Other Land Use (AFOLU) absorbed 67 $ktCO_2eq$ of GHG emissions (Climate and Environment Headquarters, 2021a).



I Figure 5. City-wide GHG emissions by year from 2005 to 2019 (Unit: ktCO2e) (Data source: Climate and Environment Headquarters, 2021a)

2.2.2 Beijing

The carbon intensity of economic activities in Beijing has decreased significantly in recent years. During the 13th FYP period (2016–2020), the carbon intensity decreased by more than 23% from the 2015 level, which exceeded the target of 20.5% delegated by the national government. In 2020, the CO_2 emission per CNY 10,000 GDP reached 0.42 tons, ranking at the best level among provincial administrations in China (Xinhua Net, 2021a).

2.3 Air quality status

2.3.1 Seoul

Particulate matters (PM) are Seoul's city-wide environmental and social problem. According to the national statistics based on a public survey in 2020, more than half of the respondents expressed considerable (43.2%) and extreme (35.7%) concern over the PM issues (Online National Statistics, n.d.). As a result, the city has taken various measures to control air pollution to ease public concerns, beginning with air quality monitoring. Table 2 shows annual statistics for air pollutants between 2015 and 2021.

I Table 2. Annual statistics of air pollutants in Seoul city (2015-2020) (Data source: SMG, n.d.a)

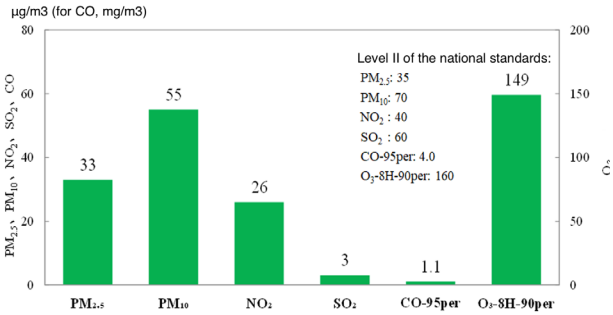
	$PM_{2.5}$ ($\mu g/m^3$)	PM_{10} ($\mu g/m^3$)	O_3 (ppm)	NO_2 (ppm)	CO (ppm)	SO_2 (ppm)
2015	23	45	0.022	0.032	0.5	0.005
2016	26	48	0.024	0.031	0.5	0.005
2017	25	44	0.025	0.03	0.5	0.005
2018	23	40	0.023	0.028	0.5	0.004
2019	25	42	0.025	0.028	0.5	0.004
2020	21	35	0.025	0.024	0.5	0.003
2021	20	38	0.028	0.024	0.5	0.003

The high concentration of PM stands out as a critical issue. The concentration of $PM_{2.5}$ fluctuates over the years, while the concentration of PM_{10} has slightly declined (SMG., n.d.a). A national report also interprets the trend similarly (National Institute of Environmental Research, 2021). In 2021, the average concentration of air pollutants were 20$\mu g/m^3$ for $PM_{2.5}$, 38 $\mu g/m^3$ for PM_{10}, 0.028 ppm for ozone (O_3), 0.024 ppm for nitrogen dioxide (NO_2), 0.5 ppm for carbon monoxide (CO), and 0.003 ppm for sulfur oxide (SO_2) (SMG, n.d.a).

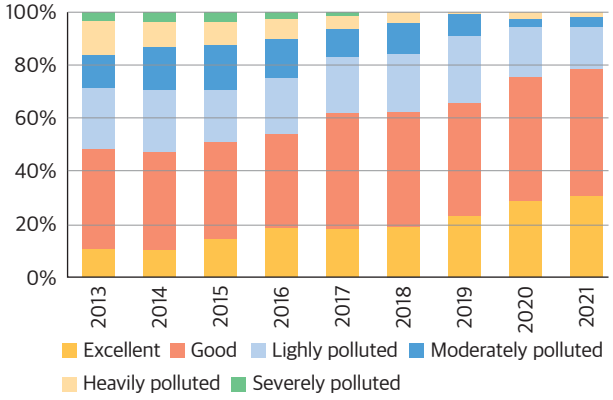
2.3.2 Beijing

Beijing significantly improved air quality in recent years. In 2021, all major air pollutants reached the National Standards Level 2 (Figure 6). Compared to 2013, the average concentrations of $PM_{2.5}$, PM_{10}, SO_2, NO_2, CO, and O_3 in 2021 reduced by 63.1%, 49.1%, 88.7%, 53.6%, 67.5%, and 18.8%, respectively. Beijing is experiencing more "good" air quality days in adherence to the National Air Quality Index. In 2021, Beijing had 286 days with "excellent" and "good" air quality, accounting for 78.9% of the year and an increase of 112 days compared to 2013.

On the other hand, Beijing suffered from eight "heavily polluted" and "severely polluted days" in 2021, accounting for merely 2.2% of the year and a decrease of 50 days compared to 2013. Figure 7 shows the increasing trend of "excellent" and "good" air quality days in Beijing. Beijing's achievement on air quality improvement also attracted international attention; UNEP published a report in 2019 systematically reviewing Beijing's 20 years of clean air action.



I Figure 6. The average concentration of criteria air pollutants in 2021 in Beijing and the national standards (Source: BEE, 2022; translated by the author)



I Figure 7. Distribution of different air quality levels in Beijing from 2013 to 2021 (Source: BEE, 2022; translated by the author)

2.4 National climate strategies

2.4.1 South Korea

GHG emissions of the Republic of Korea

Korea's GHG emissions have shown a rising trend since 2010 but have been decreasing since 2019 after reaching its peak in 2018 (Ministry of Environment, 2021). The national GHG emissions peaked in 2019 at 713.7 million tons (Mt) CO_2eq. The GHG emission increased by 149% from 1990 and decreased by 3.5% from 2018. The energy sector is the largest GHG emitter, accounting for 87.2% of the total emissions, followed by industry (7.4%), agriculture (3.0%), and waste (2.4%). Regarding GHG types, CO_2 made up the largest part accounting for 91.8% to the total emissions, followed by methane (CH_4) (3.9%), nitrous oxide (N_2O) (2.0%), hydrofluorocarbons (HFCs) (1.0%), sulfur hexafluoride (SF_6) (0.8%) and perfluorocarbons (PFC_s) (0.4%) (Ministry of Environment, 2021).

Policy background

The Korean government developed a legal framework for systematically promoting low-emission and green development strategies. As a result, the national vision for low emission and green development for the next 60 years was announced in 2008 and led to the *Framework Act on Low Carbon, Green Growth,* effective since 2010 (Ryu, 2010; The Blue House, 2009).

The Act is marked as a milestone in advancing the national approach to sustainable development and climate change. It also laid the foundation for legislative and political activities taken by the central and regional governments. The law mandated the responsibility of the government, business, and civil society on promoting a green economy, an eco-friendly lifestyle, and other low-emission actions (Ryu, 2010).

Under the *Framework Act on Low Carbon, Green Growth*, Article 9 indicates the direction for implementing the national strategy for low carbon and green growth (Korea Law Information Center, n.d.a). In 2019, the Korean Government released the *Third Five-Year Plan for Green Growth* between 2019 and 2023. With the national vision for an inclusive and green country, the government proposed three promotion strategies, five policy directions, and 20 key projects (The Office for Government Policy Coordination, 2019).

Under the *Framework Act on Low Carbon, Green Growth*, Article 40 defines the roles and responsibilities of the government in developing the *Basic Plan for Climate Change Response*. Under the Act, the government needs to create and implement the Basic Plan for the next 20 years at five-year intervals (The Government of the Republic of Korea, 2019; Korea Law Information Center, n.d.a). In 2019, the Korean Government released the Second Basic Plan for Climate Change Response as an overarching national plan for climate actions. With the national vision for a sustainable, low carbon, and green society, the government developed three core strategies (The Government of the Republic of Korea, 2019).

Firstly, to promote a transition to a low carbon society, the government sets up projects to develop a GHG emissions reduction plan for eight major sectors. It also sets a cap on total GHG emissions, considering the national GHG emissions goals and strengthening the private sector's responsibility; developing a shift and transparent evaluation and validation system between ministries of the Government (The Government of the Republic of Korea, 2019).

Secondly, to establish a robust adaptation system, the government sets up projects to enhance the climate-resilient capacity for the five major sectors (lands, water, ecosystem, agriculture and fisheries, health). It also advances a monitoring and projection system for climate change and improving climate change adaptation assessment, and mainstreaming climate change adaptation in every sector and for everyone (The Government of the Republic of Korea, 2019).

Thirdly, to enhance a climate change response framework, the government sets up projects to create new markets through developing new technologies and industries for climate change adaptation. It also enhances the capacity to negotiate and cooperate at the international level under the Paris Agreement regime; raising public awareness on climate change and promoting low carbon lifestyles; and establishing climate change response infrastructure, including regulations, organizations, and governance (The Government of the Republic of Korea, 2019).

In 2020, the Korean government announced the *Korean New Deal* to speed up the structural changes for the society and economy in the post-COVID-19 era and turn global challenges (e.g., COVID-19 and climate change) into new opportunities. This national strategy aims for a first-mover, low-carbon, and inclusive society (The Government of the Republic of Korea, 2020).

The vision is supported by two pillars: the *Digital New*

Deal and the *Green New Deal*. The more robust safety net supplements the two new deals by strengthening the basis for a people-centered and inclusive country. The government sets up 28 projects under the belt: 12 Digital New Deal projects, eight Green New Deal projects, and eight projects for stronger safety nets (The Government of the Republic of Korea, 2020).

The eight projects for the Green New Deal are categorized into three groups. Firstly, to green urban, spatial, and living infrastructure, the government demarcates projects to turn public facilities into zero-energy buildings; restore the natural ecosystem of lands, oceans, and cities; and build a clean and safe water management system. Second, to promote a low-carbon and decentralized energy system, the government sets up projects on establishing smart grids to increase energy efficiency; laying the foundation for the expansion of new and renewable energy and the just energy transition; and expanding the operation of electric and hydrogen vehicles. Finally, to develop an innovation ecosystem for green industries, the government incubates prospective green businesses and industries, laying the foundation for green innovation via research and development and sustainable financing. It also set up tasks to develop low-carbon and green industrial complexes (The Government of the Republic of Korea, 2020).

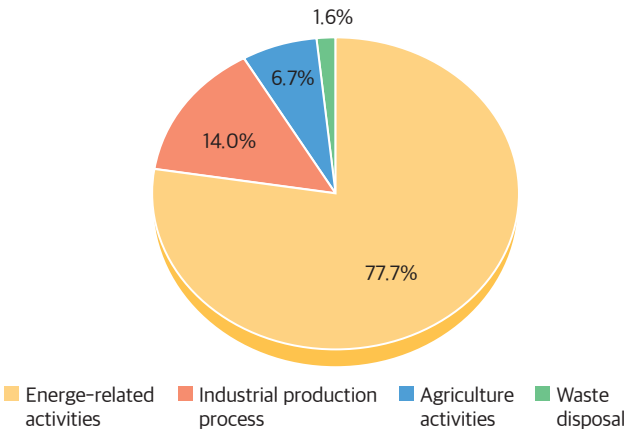
2.4.2 China

GHG emissions

According to the *China Second Biennial Update Report on Climate Change* submitted in 2019, China's total GHG emissions (excluding land-use, land-use change, and forestry (LULUCF)) in 2014 reached 12,301 Mt CO_2eq, and the GHG sinks from LULUCF were 1,115 Mt CO_2eq. Thus, China's total net GHG emissions were 11,186 Mt CO_2eq, of which CO_2, CH_4, N_2O, HFC_s, PFC_s, and SF_6 accounted for 81.6%, 10.4%, 5.4%, 1.9%, 0.1% and 0.6%, respectively. Energy activities led to most emissions, contributing 77.7% of GHG emissions. Industrial processes and agricultural activities led to 14% and 6.7% of China's GHG emissions, respectively (Figure 8).

Climate targets and strategies

The Chinese government has recently announced a series of significant climate targets. In a virtual address to the 75th UN General Assembly in September 2020, President Xi Jinping announced that China will adopt strong policies to peak carbon emissions by 2030 and

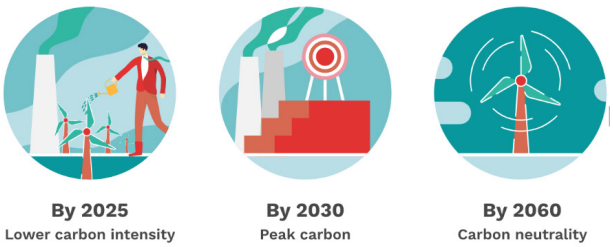


I Figure 8. GHG emissions of China by sectors in 2014 (excluding LULUCF) (Source: MEE, 2018)

achieve carbon neutrality by 2060 (Xinhua Net, 2020a). Furthermore, at the UN Climate Ambition Summit in December 2020, President Xi Jinping announced more stringent commitments for 2030 that China will:

1. Lower CO_2 emissions per unit of Gross Domestic Product (GDP) by over 65% from the 2005 level;
2. Increase the share of non-fossil fuels in primary energy consumption to around 25%;
3. Increase forest stock by 6 billion m^2 from the 2005 level; and
4. Bring wind and solar power's installed capacity to over 1.2 billion kW (Xinhua Net, 2020b).

Considering China's GHG emissions as the world's second-largest economy, realizing these targets will significantly impact global climate change mitigation. .



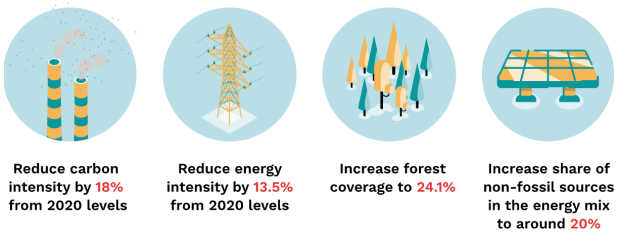
I Figure 9. China's climate goals (Source: China Dialogue, 2021)

At the leaders' summit of the 15th meeting of the Conference of the Parties to the Convention on Biological Diversity (COP15), President Xi announced that China will establish a "1+N" policy framework for carbon peak and carbon neutrality. The "1" refers to the *Working Guidance for Carbon Dioxide Peaking and Carbon Neutrality in Full and Faithful Implementation of the New Development Philosophy*, which sets out the overarching principles

of all policies that contribute to China's climate goals. In addition, the "N" includes detailed climate actions plans, primarily the following key actions:

- Optimize the energy structure
- Promote industrial transition
- Promote energy-saving, low-carbon buildings, and infrastructure
- Build a green and low-carbon transportation system
- Develop a circular economy
- Promote green and low-carbon technological innovation
- Develop green finance to expand financial support and investment
- Introduce supporting policies, such as new standards and the Climate Law
- Optimize the carbon trading market to include more sectors
- Implement nature-based solutions (NbS)

China announced several near-term climate-related targets in the 14th FYP, which is a top-level policy blueprint, including significant targets and actions for 2021-2025 (Figure 10). First, improving energy efficiency is the focus at this stage, including the targets of reducing energy intensity and carbon intensity by 13.8% and 18%, respectively, from the 2020 levels. Secondly, closely related to the energy intensity and carbon intensity targets, the government plans to increase the share of non-fossil sources in the energy mix to around 20%. Thirdly, the government aims to improve forest coverage to 24.1% as carbon sinks.



I Figure 10. The 14th FYP's climate-related targets for 2025 (Source: China Dialogue, 2021)

Climate pilot programs

Climate pilot programs are pivotal policy instruments to encourage local governments to adopt climate policies and collect experience from cities. China has implemented several national pilot programs in which Beijing directly participated. Table 3 shows some critical national climate pilot programs.

These low-carbon pilots contributed to national and Beijing's decision-making on low-carbon policies. On the one hand, these pilot practices supported Beijing to design and implement low carbon policies based on the local context, with financial and technical support from the national government. Meanwhile, Beijing's experience supported the Chinese government in designing more effective policies, reflecting how the national pilot programs incorporate bottom-up and top-down approaches.

I Table 3. China's climate pilot programs and Beijing's participation

Pilot program	Low carbon city	Low carbon small town	Low carbon industrial park	Low carbon community
Key activities	Low carbon development plans Low carbon industrial systems GHG inventory systems Accountability systems for controlling GHG emissions Low carbon lifestyle	Overall implementation plans and specific implementation plans (e.g., renewable energy, green building, and sewage pipe networks) Financial and technical support provided by the national government	Low carbon production Low-carbon technological innovation and application Carbon emission management systems Low carbon infrastructure (e.g., energy, water, heating, and waste management)	Low carbon thoughts into community planning Low carbon culture and behavior Low carbon management system Green buildings The community environment
Beijing's involvement	Beijing Municipality	Gubeikou Town	Zhongguancun Yongfeng High-tech Industrial Base, Caiyu Economic Development Zone	Several communities in Beijing

Chapter 3

Climate Strategies and Institutional Arrangement

CLIMATE CHANGE STRATEGIES AND INSTITUTIONAL ARRANGEMENT at a glance

	Seoul	Beijing
GHG reduction policies		
	The 2050 Seoul Climate Action Plan The 2050 GHG Emission Reduction Strategic Plan Comprehensive Plan for Climate Action (2022-2026)	The 13th FYP for Energy Conservation and Climate Change
Climate adaptation-specific policies		
Strategy	The Five-Year Climate Change Adaptation Action Plan (2017-2021)	The 13th FYP for Energy Conservation and Climate Change
Priorities	• Public health • Disaster risk reduction • Water management • Forest and ecosystems	• Urban planning and infrastructure development • Resilience management system development • Extreme weather response
Institutional arrangement		
Coordination group	Climate Crisis Task Force The Climate Change Action Committee	The Comprehensive Air Pollution Control and Climate Change Response Working Group
Leading organization	Seoul Climate and Environment Headquarters	Beijing Municipal Bureau of Ecology and Environment (BEE)

3.1 Climate change strategies

3.1.1 Seoul

SMG has long been aware of the climate crisis and has proactively responded through mitigative and adaptive measures. In particular, Seoul joined the C40 Cities Climate Leadership Group in 2006 and hosted the C40 Large Cities Climate Summit in 2009, at which the Seoul Declaration was adopted to specify joint countermeasures for the climate crisis.

Seoul established the legal system for responding to climate change by enacting and enforcing the *SMG Ordinance on Tackling Climate Change* in January 2009. SMG released the One Less Nuclear Power Plant (2012-2020) and the Promise of Seoul (2015) following the ordinance. In addition, SMG established and implemented the Comprehensive Climate Action Plan (2017-2021) until 2021, including GHG reduction and climate change adaptation actions.

In 2021, SMG published the *2050 GHG Emission Reduction Strategic Plan* and the *2050 Seoul Climate Action Plan* to achieve carbon neutrality by 2050. To develop a comprehensive plan, SMG has organized and operated a Climate Action Forum consisting of

2012	Phase 1 of One Less Nuclear Power Plant
2014	Phase 2 of One Less Nuclear Power Plant
2015	The Promise of Seoul
2017	Seoul City Comprehensive Climate Action Plan (2017-2021)
2020.7	2050 GHG Reduction Strategy through Green New Deal Policies
2021.1	2050 GHG Emission Reduction Strategic Plan
2021.6	2050 Seoul Climate Action Plan
2022.2	Seoul City Comprehensive Climate Action Plan (2022-2026)

I Table 4: Timeline of Seoul's climate action

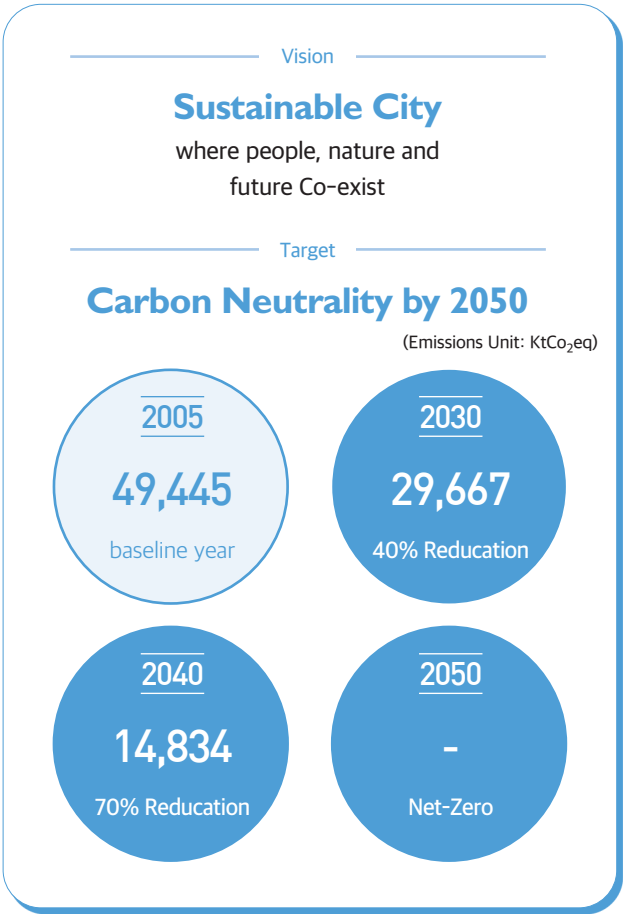
academic professors, civil groups, and experts in the climate change field since 2019. The Climate Change Forum proposed GHG reduction strategies in buildings, transportation, waste, and energy sectors to SMG. In addition, a Climate Crisis Taskforce centered on related departments was organized to review the proposed policies in depth. Based on this, SMG released the 2050 GHG Reduction Strategy through Green New Deal Policies in July 2020 and collected opinions from the public and experts to supplement the strategy. Then, SMG announced the *2050 GHG Emission Reduction Strategic Plan* in January 2021. Based on the plan, SMG submitted the *2050 Seoul Climate Action Plan* to C40, and the Plan was approved for the first time for East Asian cities in June 2021.

In 2022, SMG started to implement the Comprehensive Climate Action Plan (2022-2026), a five-year short-term plan as a step forward to achieve the 2050 plan.

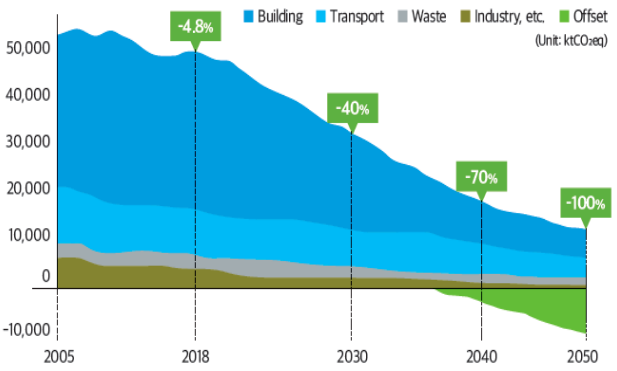
2050 Seoul Climate Action Plan

Reaching carbon neutrality by 2050 is essential for achieving the 1.5 °C targets of the Paris Agreement. In order to contribute to this target, Seoul set the vision of a "sustainable city where people, nature, and future coexist" and set the goal of achieving a carbon-neutral city by 2050.

In the 2050 Seoul Climate Action Plan, the goal of reducing GHG emission by 40% by 2030 compared to 2005 remains the same as the goal in the Promise of Seoul released in 2015. The new targets in the plan include a 70% reduction by 2040 and carbon neutrality by 2050.



I Figure 11: Vision and goals of the 2050 Seoul Climate Action Plan



I Figure 12: Seoul GHG emission pathway by sector

To achieve carbon neutrality by 2050, SMG has set policy goals and prepared specific action plans for five areas, including buildings, transportation, waste, energy, and forests. In the building sector, the key objective is to convert all buildings in Seoul into low-carbon zero-energy buildings. In the transportation sector, all internal combustion engine vehicles are replaced with zero-emission vehicles, such as EVs and hydrogen vehicles; and the core goal is to shift towards ecomobility, such as walking and cycling. The energy sector's core aim is to transition from fossil fuel-based power to new and renewable energy, such as solar and fuel cells. SMG declared a green recycling policy for the waste sector that will fundamentally reduce waste generation, promote circulation, and prohibit direct dumping into landfills. In addition, a green forest policy was proposed to expand urban parks and forests to offset greenhouse gases and improve urban resilience.

Seoul City Comprehensive Plan for Climate Change (2022-2026)

SMG established a five-year short-term action plan to achieve carbon neutrality in 2050. According to the SMG Ordinance on Tackling Climate Change, the comprehensive plan for responding to climate change is established every five years. It is a comprehensive plan including climate change adaptation and mitigation. In this plan, SMG has set a short-term GHG reduction target of 30 percent by 2026 and plans to push for ten critical tasks in the five major areas and 143 detailed projects. The plan was finalized in February 2022 after deliberation and resolution by the Seoul Climate Change Response Committee.

I Table 5. Vision and goals of the Comprehensive Plan for Climate Change (2022-2026)

Vision	"A City Safe from Climate Change"	
Goals	GHG emission reduction by 30% by 2026 A foundation for a safe city against climate change	
Key tasks	One million energy-efficient buildings	• Promotion of building energy efficiency • Supply of new and renewable energy
	The era of 10% EVs	• Promotion of EVs and charging stations
	Green space, water, and roads instead of concrete	• A park city full of forest • A city of water where water circulates • Converting roads to forest roads
	Safe city against climate disasters	• Development of a safe city against climate disasters • Protection of the public's health from heat waves and infectious diseases
	Public engagement	• Zero Waste Seoul • A public climate response campaign

I Table 6. The top ten tasks of the Comprehensive Plan for Climate Change (2022-2026)

Category	Tasks
One million energy efficiency buildings	1. Reduce emissions from buildings by promoting energy efficiency • Promotion of energy efficiency for one million old buildings (accounting for 25% of four million old buildings in Seoul) • Enforcement of "zero energy building (ZEB)" design for buildings with a total floor area of more than 100,000 m^2 in 2023 (onwards) 2. Supply new and renewable energy • Promote new and renewable energy, such as hydrothermal and geothermal (the penetration rate of new and renewable energy: 4.2% in 2021 to 12.6% by 2026 to 21% by 2030)
The era of 10% EVs	3. Promote EVs and charging stations • Expand EV charging infrastructure by more than ten times from 20,000 units in 2021 to 220,000 units by 2026 • Promote EVs from 52,000 EVs in 2021 to 400,000 EVs by 2026
Green spaces, water, and roads	4. A park city full of forest • Create and maintain the area of green spaces to 13 times that of Work Cup Park, reaching 31 million m^2 by 2026 5. Create a city of water by establishing an urban water circulation system • Create an intelligent water circulation city that utilizes discarded urban water resources (10 locations by 2026) • Expand water space through the promotion of "Stream Renaissance" 6. Change roads from "car spaces" to "walking paths" • Transit 22 car-oriented roads (28.5km) to walking path by 2030
A climate-safe city against disasters	7. Create a climate-safe city against disasters • Prevent damage from drought and flood by intensive management of water and sewage facilities • Prevent damage from heavy rain and heavy snow by strengthening inspection and diagnosis of road facilities 8. Protect public health from heat waves and infectious diseases • Expand health care visits for vulnerable groups during heat waves (290,000 cases in 2021 to 340,000 cases per year by 2026) • Better respond to new infectious diseases by upgrading the infectious disease management system
Public engagement	9. Public climate action campaign to respond to climate change • Expand the eco-friendly campaign, such as 'Seoul Gamtanhae,' to one million population 10. Zero Waste Seoul - Zero disposable café cups • Reduce 600 million disposable cups annually by 2026 • Zero the number of disposable cups by 2026.

3.1.2 Beijing

Beijing established a comprehensive climate policy framework, which covers general climate strategies (e.g., climate five-year plans), sector plans (e.g., green building), and specific actions (e.g., coal reduction) in different time frames. Table 7 shows vital climate strategies issued by Beijing since 2010.

The FYP for Energy Conservation and Climate Change provides comprehensive short-term strategies to guide Beijing's key climate policies every five years. It includes leading targets, policies, and projects. Table 8 shows Beijing's climate-related targets and achievements during the 12th and 13th FYP periods, demonstrating the progress of Beijing's climate action from 2010 to 2020. Notably, the total energy consumption and coal consumption reduced sharply, which led to a significant reduction of CO_2 emissions per unit of GDP. Meanwhile, the share of renewable energy increased steadily, but Beijing still has much potential to deploy more renewable energy in the city.

I Table 7. Beijing's key climate strategies and plans from 2010 to 2021

Categories	Plans	Date
Climate FYPs	12th FYP for Energy Conservation and Climate Change	2011
	13th FYP for Energy Conservation and Climate Change	2016
	14th FYP for Energy Conservation and Climate Change	Forthcoming
	Beijing's Carbon Neutrality Roadmap	Forthcoming
Climate-related FYP	12th FYP for Energy Conservation of Residential Buildings	2011
	12th FYP for Energy Development	2011
	12th FYP for Green Beijing Development and Construction	2011
	13th FYP for Ecological and Environmental Protection	2016
	13th FYP for Public Engagement on Energy Conservation and Circular Economy	2016
	13th FYP for Energy Development	2017
	13th FYP for New Energy and Renewable Energy Development	2016
	13th FYP for Energy Conservation of Residential Buildings	2016
	13th FYP for Transport Development	2016
	13th FYP for Smart Transport Development	2017
	13th FYP for Circular Economy Development	2016
	13th FYP for Industry Transformation and Upgrade	2017
	13th FYP for Garden, Forest, and Green Space Development	2016
	14th FYP for Ecological and Environmental Protection	2021
Climate-related Action Plan	Beijing Clean Air Action Plan (2011-2015)	2011
	Clean Air Action Plan (2013-2017)	2013
	Implementation Opinions on Further Promoting Development of Geothermal Energy and Utilization of Heat Pump Systems	2013
	Work Plan for Accelerating Coal Reduction and Clean Energy Development (2013-2017)	2013
	Green Building Action Plan	2013
	Implementation Plan for Promoting Standardization on Energy Conservation, Low-Carbon and Circular Economy (2015-2022)	2015
	Implementation Opinions to Further Promote Clean, Efficient and Safe Energy	2015
	Pilot Implementation Plan for Energy Efficiency Leader (2016-2020)	2016
	Public Building Energy Efficiency Improvement Action Plan (2013-2017)	2016
	Notice on Issuing the Action Plan for Green and Low-Carbon Circular Development of Beijing Economic and Technological Development Zone (2019-2025)	2019
	Notice on Issuing Opinions on Further Accelerating the Application of Heat Pump System and Promoting the Implementation of Clean Heating	2019
	Notice on Further Supporting the Promotion and Application of Solar Power Generation Systems	2020
Annual measures	Annual Work Plan for Clean Heating in Rural Areas in Winter	2013-2018
	Notice on Conducting Energy Conservation Supervision Work in 2020	2020
	Key Points of Beijing's Energy Work in 2021	2021
	Key Points of Clean Production Promotion in 2021	2021

(Notes: This table only highlights the key plans and policies)

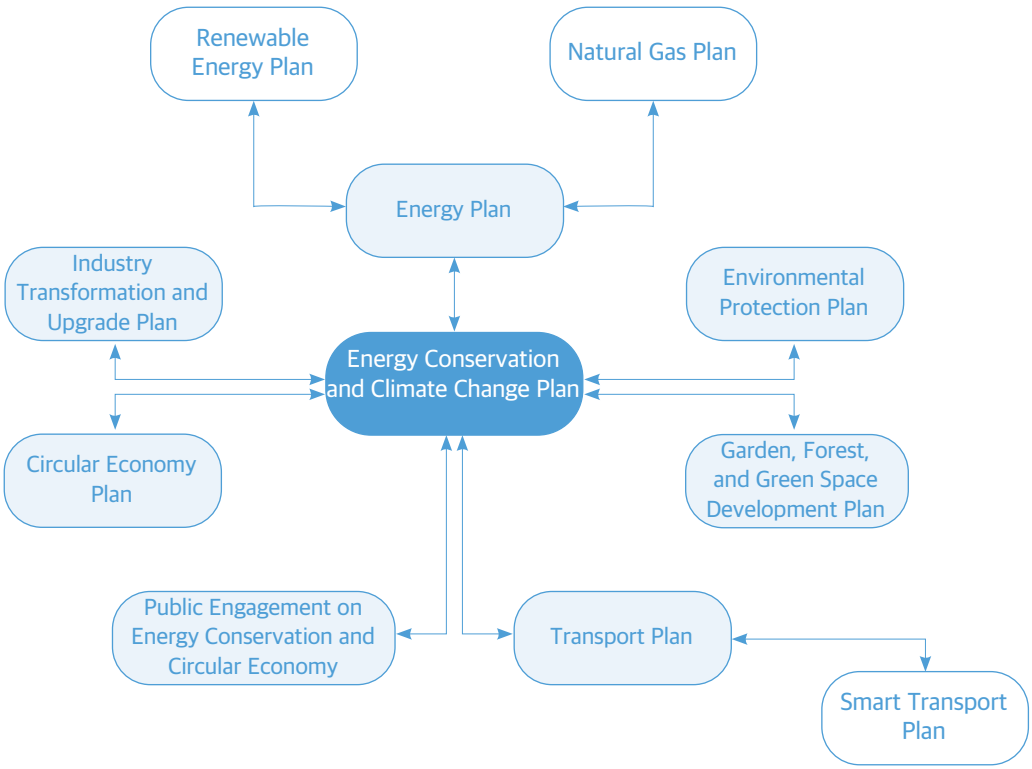
I Table 8. Beijing's 12th FYP and 13th FYP for energy conservation and climate change (Data source: Beijing Municipal Government, 2011, 2016)

Categories	12th FYP		13th FYP	
	Target	Achievement	Target	Achievement
Energy consumption change per CNY 10,000 GDP	-17%	-25.08%	-17%	-21%
CO_2 emissions change per CNY 10,000 GDP	-18%	-30%	-20.5%	>26%
Coal consumption (Mt)		11.65	<9	1.73
Share of new and renewable energy	6%	6.5%	>8%	10.4%

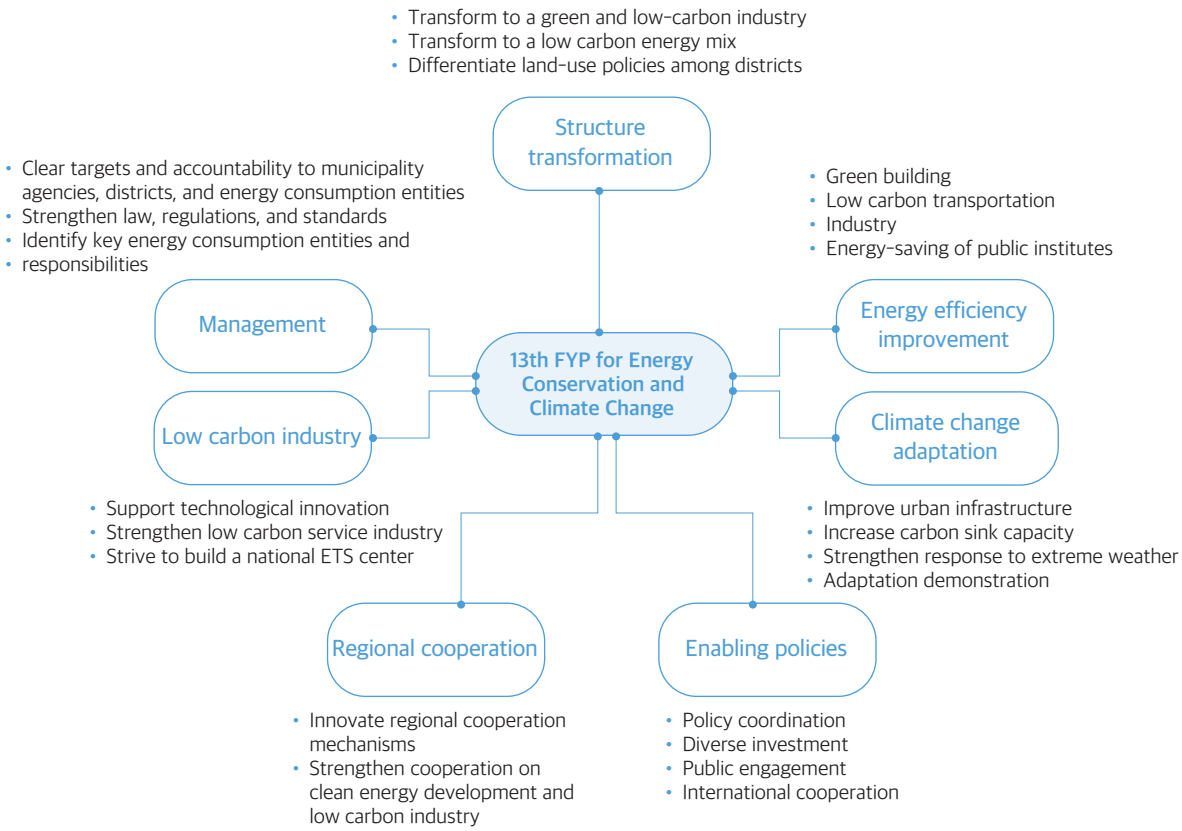
(Notes: For 12th FYP and 13th FYP, the baseline year was 2010 and 2015, respectively; the target year was 2015 and 2020, respectively.)

Beijing's *13th FYP for Energy Conservation and Climate Change* set several climate-related targets, one of which was peaking CO_2 emissions by 2020. Beijing's carbon peaking timeline was ten years earlier than the national target and was among the first batch of cities committed to carbon peaking. District governments have specific annual emission reduction targets in alignment with the municipal government.

Beijing also released other climate-related FYPs, which contributed to achieving the targets set in the *13th FYP for Energy Conservation and Climate Change*. Figure 13 shows the interconnection between the *13th FYP for energy conservation and climate change* and other sectoral FYPs. These plans constitute a comprehensive climate policy system but need to be streamlined further in the upcoming carbon neutrality roadmap.



I Figure 13. The climate change FYP and other climate-related FYPs for the 13th Five-Year period



I Figure 14. Key climate actions included in Beijing's 13th FYP for Energy Conservation and Climate Change

Beijing's *13th FYP for Energy Conservation and Climate Change* outlines multiple climate actions for 2016–2020 that reflect a comprehensive horizontal and vertical policy framework. Horizontally, the plan covers cross-sectoral actions, including energy, industry, land use, and others (Figure 14). The plan layout responsibilities and activities at the regional, municipality, district, and energy consumption entity levels in terms of vertical coordination.

For the 14th FYP period, Beijing set several climate targets by 2025. First, the total carbon emissions achieve a steady decline after peaking and down more than 10% from the peak. Second, the city will achieve an 18% reduction in CO_2 emissions per unit of GDP. It is worth noting that these two targets excluded carbon emissions from air passenger and cargo transport. Third, renewable energy consumption reaches around 14% (Beijing Municipal Government, 2021d).

3.2 Climate change adaptation

3.2.1 Seoul

According to Article 38 of the *Enforcement Decree of the Framework Act on Low Carbon, Green Growth*, SMG establishes a detailed implementation plan for climate change adaptation every five years in line with the national climate adaptation measures. SMG shows a comprehensive climate change response plan, including climate change adaptation actions.

SMG develops climate change adaptation actions based on assessing climate change impacts and vulnerabilities by sector. First, using the Climate Change Vulnerability Assessment Support Tool (VESTAP) developed by the Ministry of Environment, SMG analyses climate exposure, sensitivity, and adaptability to evaluate climate change vulnerability. Then, SMG creates adaptation measures based on identifying essential adaptation issues.

The subsection below provides detailed information about the implementation plan for climate change adaptation measures from 2017 to 2021.

Public health

SMG aims to minimize damage to vulnerable groups under climate change and improve their adaptability to abnormal climates for public health. Actions respond to heatwaves, heatwaves, which are direct effects of climate change, and infectious diseases and air pollution, which are indirect effects.

Response to heatwaves

The central policies targeting heatwaves include establishing heat shelters and safety systems and the protection and management of vulnerable groups. SMG designates senior citizen centers, welfare centers, welfare facilities, community centers, and government offices as "heat shelters" to protect the vulnerable in the event of a heatwave and operates them for four months, from May to September every year. In addition, SMG manages a heatwave disaster response headquarters every summer and delivers information through communication and text service to vulnerable groups and outdoor workers. To protect the vulnerable group, SMG has established and operated a protection system for residents of Jjokbangchon and homeless people. In addition, healthcare visits are implemented for them, such as the elderly living alone, chronically ill, and the disabled. In addition, SMG distributes health care and response manuals to the public at heatwave vulnerable sites and strengthens measures to protect workers at construction sites by implementing a heatwave impact forecast system and conducting on-site inspections.

Response to infectious diseases

SMG operates an infectious disease monitoring system. In particular, regarding the recent COVID-19 response, SMG protects citizens' health by implementing social distancing accordingly and making it mandatory to wear masks. SMG also put efforts on preventing various diseases, such as strengthening the rapid response system for food poisoning and intensively managing facilities of concern.

Response to air pollution

In order to manage air pollution, SMG designates and manages an intensive fine dust management zone and operates an air pollution forecast warning system to strengthen monitoring and forecasting. Firstly, among the areas where the concentration of fine dust is high, the areas are designated as concentrated fine dust management areas to protect the health of the vulnerable. Secondly, alerts are issued when the warning predicts air pollution to prevent damage and population exposure to polluted air.

Disaster management

SMG established a forecast warning system regarding disaster management and operated a rapid response system to respond to storms, floods, heavy snow, and cold waves.

Response to storms and floods

SMG implements several policies to strengthen emergency response capacities, improve recovery capacities for the vulnerable, and strengthen safety in flooded areas. SMG installs a management facility for river crises to enhance its ability to respond to storms and floods. Automatic warning facilities, text messages, and warning lights are managed, and additional installations are planned after checking the target site every year. In addition, SMG prepares and uses disaster maps to quickly evacuate from flooded areas in the event of storm and flood damage. In addition, SMG provides information so that vulnerable people can subscribe to storm and flood insurance and supports insurance premiums. SMG installs sewage storage facilities for flooded areas, maintains sewage pipes, and expands rainwater storage facilities. SMG also plans to improve the old facilities of rainwater pump stations to cope with heavy rains.

Response to heavy snow and cold waves

SMG expands automatic liquid spraying devices to prevent road freezing during heavy snow and cold waves. Furthermore, SMG has private task forces to remove snow in public spaces. In addition, SMG established and used a cold wave situation management system in winter while promoting measures to protect homeless people during cold waves.

Water management

Water management aims to stably manage water quantity and quality during water shortages and improve the capacity to respond to flood damage. SMG also takes action to restore the soundness of the distorted water circulation system due to urbanization.

Quantity management

In order to manage water quantity, SMG plans to expand the installation of water reuse facilities, such as rainwater facilities, and expand and supply heavy water and renewable water. In addition, SMG plans to extend

water level auxiliary observation network facilities and emergent water supply facilities to use groundwater resources sustainably in the event of a disaster. To minimize the leakage in the water pipe, the Seoul Metropolitan Government plans to prevent leakage and overhaul old water pipes through systematic leak detection.

Water quality control

SMG plans to establish nine reservoirs by 2027 to prevent water pollution caused by combined sewage overflows (CSOs) in confluence sewer lines for water quality management. SMG also plans to expand and install initial water treatment facilities in all water regeneration centers by 2030 to treat high concentrations of initial water flowing from public sewage treatment facilities during rainfall. In addition, SMG strengthens the management of non-point pollutants to prevent water pollutants from flowing into the Han River.

Water circulation restoration

SMG implements policies to restore water circulation, such as reducing impermeable areas. In addition, SMG promotes various projects to restore the soundness of the distorted water circulation system due to urbanization. The water circulation recovery policies have several key targets. First, SMG aims to reduce impermeable surfaces and continuously increase spaces with natural circulation functions. Second, SMG also introduces a segmented management system to reflect local characteristics and diversify projects.

Seoul enacted the *Water Circulation Recovery Ordinance* and established a basic plan for rainwater management. Based on the ordinance and the plan, SMG implements the rainwater circulation village project, which is designed to promote rainwater circulation in the village using rainwater management facilities, such as water permeability block packaging, penetration measurements, rainwater piggy banks (used to store and reuse rainwater), and rainwater reservoirs. SMG has developed 13 eco-friendly rainwater villages from 2016 to 2019. Seoul will continue to promote these water circulation policies to reduce heatwaves and manage water smoothly.

Forest and ecosystem

For the forest and ecosystem sector, SMG aims to restore forests around cities, expand urban green areas, and revitalize urban agriculture to enhance adaptability to climate change. Significant policies include preventing forest disasters, such as forest fires and landslides, conservation of biodiversity, and improving urban green functions.

Prevention of forest disasters

In order to prevent and quickly respond to forest fires, SMG operates a forest fire prevention and response headquarters, a forest fire prevention team, and a professional investigation team; and establishes an urban forest fire system. In addition, to prevent landslides, a landslide site prevention team is operated to manage landslides in vulnerable areas, and an integrated slope management system is established and utilized. In addition, to improve the resilience of forest functions, SMG plans to continuously promote afforestation projects, biological habitat spaces, pest control, and hiking trail maintenance.

Biodiversity conservation

SMG established a biodiversity strategy and implementation plan and systematically implemented related projects, including designating and monitoring indicator species and creating a biodiversity network. SMG is also designing continuous planting of street trees for the heat island phenomenon and heavy rain and is conducting an eco-cool project to create rooftop greening, wall greening, and gardens at schools.

Function improvement of urban green areas

In order to enhance the function of urban green areas, SMG created a carbon-offset forest based on the participation of private companies and the public in Hangang Park and Bukhansan Mountain. The carbon offset forest project refers to a system in which the government certifies the amount of carbon absorbed by local governments and companies obligated to reduce greenhouse gas emissions through tree planting, which can not only absorb carbon dioxide but also help adapt to climate change.

In addition, SMG developed and distributed urban plant factory models to revitalize urban agriculture and operate urban farming schools. SMG also plans to create a vertical garden in the city center that is expected to contribute to alleviating the heat island phenomenon in the city and reducing the concentration of fine dust through wall greening, rooftop garden, and green street area.

3.2.2 Beijing

Beijing has already witnessed negative impacts caused by climate change, such as floods and heat island effects, which lead to severe life and property losses. Adapting to climate change is necessary for Beijing to build a resilient city and counter climate change threats. In the *13th FYP for Energy Conservation and Climate Change*, Beijing emphasized key actions on climate change adaptation. In 2021, the Beijing Municipal Government released the *Opinions on Accelerating the Construction of Resilient Cities*, laying out measures for resilience development (Beijing Municipal Government, 2021b). Beijing aims to complete a resilient city assessment indicator system and a standard system and build 50 resilient communities, districts, and projects by 2025. By 2035, Beijing aims to achieve significant progress in constructing a resilient city.

Based on the impact assessment of climate change, Beijing's climate change adaptation strategy focuses on three areas: (1) urban planning and infrastructure development, (2) resilience management system development and (3) extreme weather response.

Urban planning and infrastructure development

Integrating climate change elements into urban planning

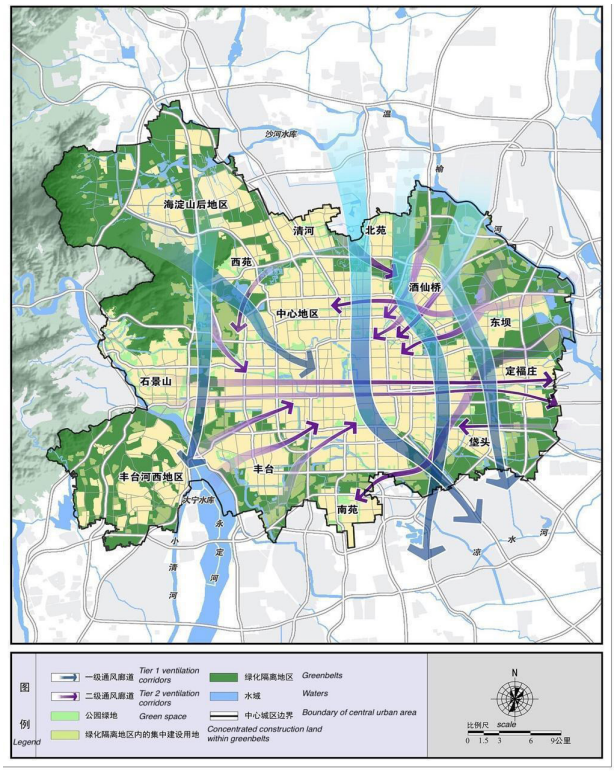
Beijing mainstreams climate-responsive urban planning in both old and new city development by retrofitting and regenerating the old districts. The government considers mid-term and long-term climate change impacts while planning, designing, and approving infrastructure renovation projects and new infrastructure projects. In addition, the government strengthens vital infrastructure, such as fire-fighting facilities and disaster prevention facilities. Beijing strictly controls building height and density to cope with the hazards, such as floods and the urban heat island effect. Beijing also plans urban ventilation corridors and water systems to integrate green spaces, rivers, and other public spaces (Beijing Municipal Government, 2016).

Improving infrastructure's adaptation capacity to climate change

Beijing improves the city's infrastructure's adaptation capacity by upgrading standards and constructing critical infrastructure. For example, Beijing upgraded construction standards for several critical infrastructure systems, such as energy, waste management, water supply, wastewater treatment, and transportation. The city also promotes NbS by using ecosystem services of the city's green spaces for risk prevention and reduction.

The Sponge City program is an instrumental infrastructure program for climate change adaptation in Beijing because the city faces flood and water scarcity risks. Therefore, the Sponge City program addresses these two challenges simultaneously. In 2017, Beijing published the *Implementation Opinions on Promoting the Construction of Sponge Cities*, laying out key actions to promote sponge city development. Firstly, Beijing integrated sponge city-related elements, operation requirements, and technical standards into urban planning and development. Secondly, Beijing set different strategies for old and new urban areas. For new urban areas, the sponge city must be integrated into the planning and implemented on a large scale.

On the other hand, city retrofitting projects must be integrated with sponge city development in older districts. Thirdly, sponge city concepts are also mainstreamed into different construction projects, such as buildings, roads, and squares. For example, new buildings with a planned land area of over 2,000 m^2 must be equipped with rainwater collection and utilization facilities. Fourthly, Beijing applied NbS into the Sponge City Program by conserving and utilizing the ecosystem services of green spaces, rivers, and lakes to support rainwater collection, flood control, and water purification.



I Figure 15. Ventilation corridor planning map in the central areas of Beijing (Source: BMCPNR, 2018)

The urban ventilation corridor is another critical infrastructure project in Beijing. According to the *Beijing Urban Master Plan (2016–2035)*, Beijing plans to develop an urban ventilation system comprising five Tier 1500 meter-wide ventilation corridors and multiple Tier 280 meter-wide ventilation corridors (Figure 15). The project reduces the heat island effect and air pollution by increasing airflow in the city as well as generating co-benefits, such as connecting different ecological lands and preserving ecological systems.

Developing a smart energy system

Beijing has been developing a smart management system to improve the system's resilience in adapting to climate change. The city has developed smart management systems for various sectors, such as building, transportation, and urban public lighting, to promote intelligent monitoring and management of energy consumption and carbon emission activities. They incorporate advanced IT technologies, including the Internet of Things (IoT), Big Data, and cloud computing. Beijing also strengthened coordination and co-supply gas, power, and heat systems. Meanwhile, Beijing develops smart grids and promotes demand-side power management. These policies enhance energy security under extreme conditions, such as floods and heatwaves.

Resilience management system development

Building a resilience management system

Beijing integrates the requirements of resilient cities into urban regulation. The city improves the resilient planning indicator system and formulates special resilient city development plans. The city also develops resilient city standards and evaluation systems and promotes resilience development standards in various sectors. In the resilience management system, Beijing strengthens the extreme response system by conducting emergency plans, assessments, and updates, which will be discussed below.

Strengthening risk prediction, monitoring, and control capabilities

Beijing improves risk prediction, monitoring, and control capacities by deploying advanced technologies and systems. Firstly, Beijing builds a comprehensive and intelligent emergency management platform and promotes open sharing of data and information from multiple sources to improve risk assessment and early warning capabilities. Secondly, Beijing develops a city sensor network by interconnecting various sensor systems for critical objects, including extreme weather, forest fires, major infectious diseases, traffic, and gas pipelines. Thirdly, Beijing improves the risk prevention and control system by improving the urban risk map, implementing the urban safety examination system, and updating the disaster risk database.

Extreme weather response

Releasing the Beijing Municipality Meteorological Disaster Prevention Regulation

In 2018, Beijing released the *Beijing Municipality Meteorological Disaster Prevention Regulation* (Beijing Meteorological Disasters Prevention Regulation, 2018). The regulation provides a legal basis for preventing and managing natural disasters that are predicted to increase in frequency and magnitude. In addition, the regulation offers several benefits for disaster management. Firstly, it emphasizes integrating disaster prevention into daily work routines. For example, the government must prepare specific budgets for climate risk prevention. Secondly, the regulation sets clear responsibilities for relevant departments, including the meteorological service department, natural resources management department, and other municipal departments. Thirdly, it states that the government must regularly conduct a climate risk assessment and establish a climate disaster information-sharing platform to promote community engagement in climate disaster management. Fourthly, the regulation indicates responsibilities and accountabilities for misbehavior that has caused severe consequences.

Improving emergency response capabilities for extreme weathers

Beijing has developed and strengthened a city-wide climate monitoring and natural disaster warning system. Beijing conducted climate disaster risk and loss assessments at the various districts to understand climate change impact better. Based on the assessment results, the government designed emergency plans and collaboration mechanisms to combat different climate disasters. Beijing has also been developing a collaborative and participatory climate change risk management system, incorporating professional disaster rescue and relief teams.

Improving the adaptive capacity of key sectors and vulnerable groups

The city government distinguished between normal and extreme climate risks based on the risk assessment study and established a multi-sectoral, multi-subject, and cross-region collaborative governance and decision-

making mechanism. Furthermore, Beijing put particular attention on public health by conducting research and improving public awareness of the adverse health impact of climate change. Meanwhile, the government strengthened the health impact monitoring network and database platform and improved the rapid response capacity for public emergencies. The vulnerable groups, such as the elderly, children, and people with reduced mobility, are more exposed to risks; thus, the city planners are attentive to improving their health care services.

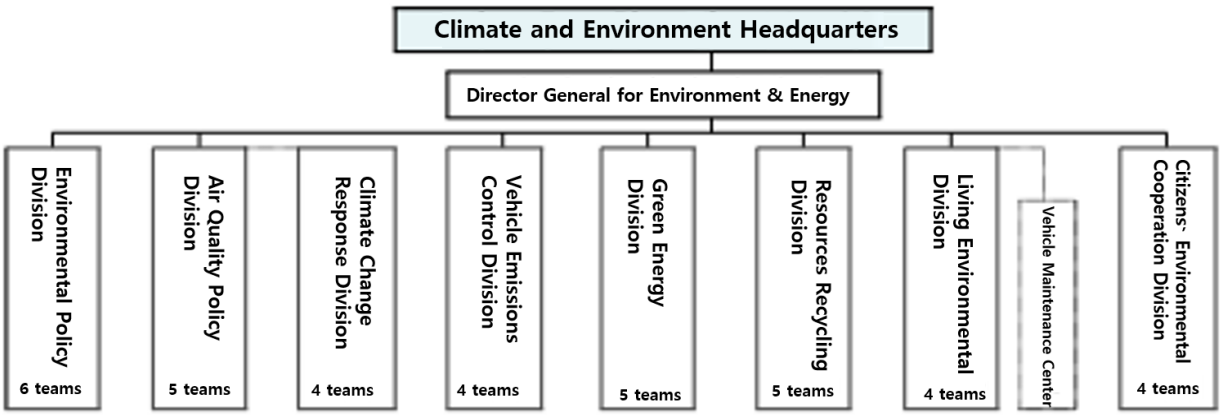
3.3 Institutional arrangement

3.3.1 Seoul

SMG is tackling climate change with related headquarters, such as Climate and Environment Headquarters. Today, Seoul Climate and Environment Headquarters ("Headquarters") takes the lead in designing and implementing climate action policies in the city (Climate and Environment Headquarters, 2021b). A need to take consistent and effective climate actions led to the establishment of the Headquarters. The unit responsible

I Figure 16. The organization structure of Seoul Climate and Environment Headquarters

Divisions	Responsibilities
Environmental Policy Division	• Set the organization's vision for climate action • Cooperate with environmental agencies • Promote international cooperation on climate and environment • Carry out environmental impacts assessment • Improve daily life inconvenience including bad smell and noise
Air Quality Policy Division	• Design and implement a comprehensive plan for air quality improvement • Conduct an investigation, analysis, and research on air quality • Manage air quality of multi-use facilities and air pollutant emission facilities
Climate Change Response Division	• Develop a mid-and long-term hydrogen roadmap and GHG inventory • Promote the expansion of eco-vehicles • Promote the transition to zero-energy building • Increase building energy efficiency
Vehicle Emissions Control Division	• Facilitate a low-emissions scheme for vehicles • Detect internal slippage of vehicles and monitor GHG emissions • Implement Green Rating system • Control and operation of old-diesel vehicles
Green Energy Division	• Develop a comprehensive energy plan • Perform tasks related to urban gas and electricity • Promote the deployment of eco-boilers • Install and expand new and renewable energy generators, including solar panels and fuel cells
Resources Recycling Division	• Manage metropolitan landfills and resource recovery facilities • Promote the reduction of using disposable products • Promote a policy on separating and putting out recyclable materials • Promote upcycling culture
Living Environment Division	• Formulate and implement a plan for cleaning up the city and roads • Manage industrial waste • Reduce and treat food waste in a stable manner
Citizens' Environmental Cooperation Division	• Develop and implement energy projects with public engagement • Form energy self-sufficiency villages • Implement an eco-mileage scheme • Activate education on environment and energy
Vehicle maintenance center	• Maintain and repair vehicles with a special purpose, such as cleaning, flood defense, and snow removal



I Figure 17. Organizational chart of the Climate and Environment Headquarters

for climate actions has been reshuffled from the Earth Environment Team under the Clean Environment Headquarters to the Climate and Environment Headquarters, looking at climate and environment in a more holistic manner (Lim & Suh, 2012).

Seoul Climate and Environment Headquarters includes eight divisions comprising 37 teams and an additional office. The following shows the structure of the Seoul Climate and Environment Headquarters (Climate and Environment Headquarters, 2021e).

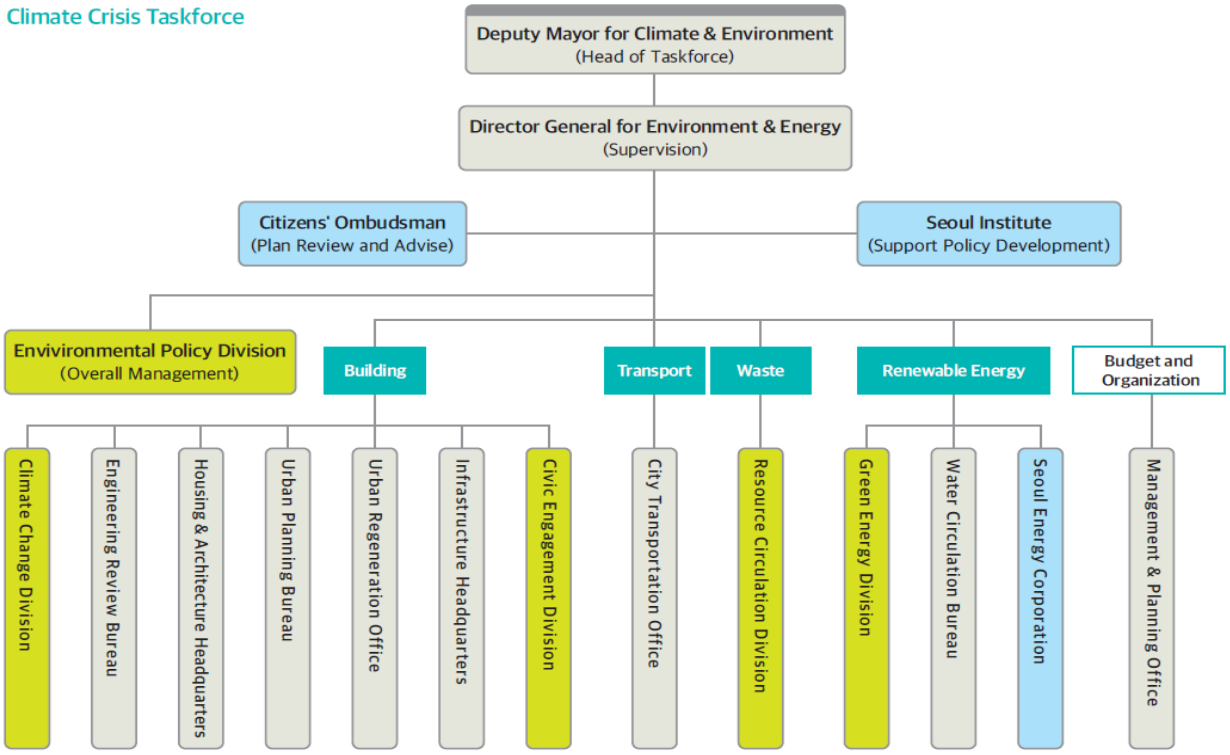
Meanwhile, the SMG organized and operated the Climate Crisis Taskforce while establishing the 2050 Seoul Climate Action Plan. A governance system was mainly established by the Climate and Environment Headquarters to review tasks in each sector, such as building, transportation, and waste for the participation of Housing Policy Division, the Water Circulation Safety Bureau, and the Green Seoul Bureau. As a result of meeting by the Climate Crisis Taskforce, practical projects to help reduce GHG emissions were discovered, and all departments of Seoul began to actively participate in GHG reduction.

For specific strategies and plans, Seoul sets up taskforces to promote coordination. For example, to develop the 2050 Seoul Climate Action Plan, SMG established the Climate Crisis Taskforce in March 2021 to coordinate government agencies. The Taskforce reviewed proposals and recommendations provided by the Climate Action Forum and the Seoul Institute, the municipal-linked think tank. The Taskforce also held meetings to discuss the best measures for critical sectors, including building, transport, energy, and waste (Climate and Environment Headquarters, 2021b).

In addition, the SMG is forming a Climate Change Countermeasure Committee based on the SMG ordinance on tackling climate change. The Climate Change Countermeasure Committee plays a role in establishing and implementing major policies related to climate change, such as the Comprehensive Plan for Climate Action, and deliberating and resolving major city agendas. The Climate Change Countermeasure Committee consists of 20 members, including one chairperson, who is the Vice Mayor 1 for Administrative Affairs. The ex officio members consist of the head of the Climate Environment Headquarters, the head of the City Transportation Office, the head of the Housing Policy Division, Director General of Urban Planning Bureau, Director General of Green Seoul Bureau, and the Director General of Water Circulation Safety Bureau.

To maximize the efficiency and effectiveness of the climate actions, SMG closely cooperates with other partners. Cooperation with the national government is essential to ensure smooth actions against climate change. With the national government, National Assembly, and Seoul City Council, SMG makes collaborative efforts to amend laws and regulations, laying a legislative foundation for climate action.

In addition, SMG works with affiliated research agencies, such as Seoul Institute, Seoul Institute of Technology, and Seoul Research Institute of Public Health and Environment, to enhance informed decision-making and evaluate policy results.



I Figure 18. The Climate Crisis Taskforce in Seoul (Source: Climate and Environment Headquarters, 2021a)

3.3.2 Beijing

In 2021, the national government of China set up the Carbon Peak and Carbon Neutrality Work Leading Group to guide and coordinate the efforts towards China's climate targets. Specific task groups have been established under this leading group. For example, a group composed of various ministries, institutes, and associations was created to promote and coordinate the monitoring, reporting, and verification (MRV) systems for carbon emissions (NRDC, 2021).

Similar to the national government, the Beijing Municipal Government established the *Beijing Leading Group on Climate Change, Energy Conservation, and Emission Reduction* to coordinate work among relevant departments. In 2018, the Beijing Municipal Committee of the Communist Party of China created the Ecological Conservation Commission, under which the *Comprehensive Air Pollution Control and Climate Change Response Working Group* were established. The group supports integrated GHG emissions and air pollution reduction policies. This Working Group also strengthens coordination among relevant municipal bureaus, such as the BEE and the Beijing Municipal Commission of Development and Reform (BMCDR).

BEE is the leading organization with a mandate for environmental protection and climate change response. BEE coordinates, designs, and implements climate policies at the municipality. Figure 19 shows the structure of BEE's institutional arrangement and key climate policy mandates. Under BEE, the Climate Change Response Division maintains scientific and international cooperation responsibilities, contributing to the global climate agenda.

I Figure 19. The organizational structure and key climate change responsibilities (excluding administration and inspection offices) (Data source: BEE website)

Categories	Offices	Mandates
Internal organization	Research Office	
	Regulation and Standards Division	
	General Management Division	
	Natural Ecological Conservation Division	
	Atmospheric Environment Division	
	Water Ecology and Environment Division	
	Soil Ecology and Environment Division	
	Solid Waste and Chemical Division	
	Radiation Safety Supervision Division	
	Vehicle Emission Management Division	
	Pollution Source Management / Emergency Management Division	
	Ecological Environment Monitoring Division	
	Science and International Cooperation Division / Climate Change Response Division	• Design and implement environmental technology policies, plans, and standards • Organize ecological and environmental science research • Organize environmental conservation technology demonstration, application, and public communication • Responsible for international cooperation and communication • Organize to design and coordinate to implement climate change and GHG emission reduction strategies, policies, and action • Responsible for conducting GHG emission inventory and monitoring GHG emission control targets • Organize the implementation of Clean Development Mechanism (CDM) work
	Communication and Education Division	
Subordinate institutes	Beijing Climate Change Management Center	• Conduct research on climate change policies, plans, and systems • Commissioned by BEE, responsible for specific work on international cooperation and projects on climate change • Support ETS work • Responsible for climate change publicity, consulting services, and data and information collection and collation
	Other institutes	
Coordinating organization	Office of the Leading Group for the Second Census of Pollution Sources in Beijing	
	Office of Beijing Heavy Air Pollution Emergency Command	

Chapter 4

Air pollutant and GHG emission reduction strategies

Cities consume two-thirds of the world's primary energy. The global fight for climate change is essentially an energy challenge as energy accounts for 75% of the global GHG emissions. Therefore, energy transition is at the heart of the city's climate neutrality goals. Energy is needed for powering transport, heating and cooling at buildings, supporting commercial activities, and others. Cities' fossil-based energy systems generate high carbon footprints, leading to GHG emissions and air pollution. Their energy demand is exacerbated by increasing population, economic activities, and expectations in living quality. Poor urban planning that leads to urban sprawl also drives up transport demands and energy intensity in transport as the travel distance increases. Furthermore, buildings account for 28% of global energy-related GHG emissions, and the share may be even more significant in metropolitan cities.

To strengthen energy security and build sustainable energy systems in cities, there is a strong need to enhance energy efficiency and conservation to reduce the overall energy demand for the same energy services while facilitating renewables to achieve a higher energy share. Therefore, cities are key actors to champion policy and technological innovation in enhancing energy efficiency and reducing dependence on carbon-intensive energy systems through renewable energy. Most of Seoul and Beijing's sectoral strategies started from an air quality improvement perspective. Still, they evolved towards addressing global climate change as it became more prominent in the cities' political agenda.

Against this background, this chapter encompasses three main sections. It will first present air quality management policies and strategies to provide more context and background and then present the GHG mitigation measures in the energy, building, and transport sectors. Finally, the chapter will provide some insights and findings on Seoul and Beijing's integrated air quality and climate change co-control interventions, as this is one of the cores of the bilateral partnership.

4.1 Air quality management policies

4.1.1 Air quality management policies and actions

Air quality management in Seoul and Beijing is closely connected to the two cities' efforts on climate change. Both cities are highly aware of air pollution, thus putting much effort into improving air quality. Meanwhile, academic research revealed that air pollutants and GHGs share many sources, particularly the energy and transportation sectors. This section provides an overview of the two cities' air quality policies and interventions to support the two cities' efforts on integrated climate and clean air action.

4.1.1.1 Seoul

Seoul Action Plan for the Second Metropolitan Air Quality Control

The SMG developed a five-year detailed implementation plan based on the Second Metropolitan Air Quality Control Basic Plan (2015-2024) established by the Ministry of Environment according to the Special Act on the Improvement of Air Quality in the Specified Area under Air Quality Control. They also announced their second implementation plan in 2020, providing guidelines from 2020 to 2024. Both plans include major reduction strategies to achieve the target concentration for improving the air quality, the emission and forecast of air pollutants by emission source, and the target concentration. It aims to achieve $PM_{2.5}$ of 17㎍/㎥, and PM_{10} of 30㎍/㎥ by 2024. SMG aims decrease $PM_{2.5}$ by 25% (1,677 tons), PM_{10} by 28% (6,048 tons), NO_x by 20% (48,705 tons), and VOC_s by 5% (61,280 tons).

The SMG established 77 emission reduction measures in four sectors to achieve the target emissions, including road mobility, non-road mobility, air pollutant emission facilities, and life pollutants. Phasing out the old diesel vehicles and construction machines while expanding the supply of clean vehicles and construction machinery are the key strategies for road and non-road mobile pollutant management. The management strategy of facilities causing air pollution is controlling the total

amount of air pollutant emissions from big companies and providing economic and technological support to enhance their facilities in small companies. The management of household pollutants includes expanding the supply of eco-friendly boilers for home use, strengthening fugitive dust management at construction sites, creating forests in living areas, and expanding the supply of new and renewable energy. Finally, with the long-term emission reduction strategy, short-term intensive reduction measures are applied to protect the public's health from high concentrations of fine dust in winter and early spring.

4.1.1.2 Beijing

According to the UNEP (2019), Beijing has established a comprehensive and increasingly effective air quality management system in the last 20 years. This system comprises five success factors: comprehensive legislation and enforcement mechanism, systematic planning, robust local standards, strong monitoring capacity, and high public environmental awareness.

Beijing has developed several clean air plans, including five-year environmental protection plans, clean air action plans, and annual measures. To back implementation, Beijing has significantly invested in clean air actions since 2013 (Figure 20), one of the deciding factors for Beijing's air quality improvement in recent years.

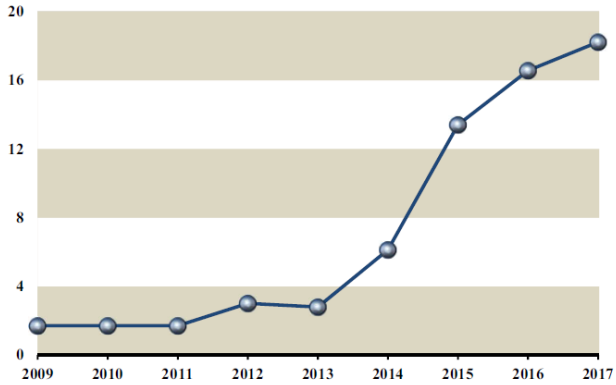


Figure 20. Beijing's financial investment in clean air actions between 2009 and 2017 (Billion CNY) (Source: UNEP, 2019)

Beijing's annual air quality management plan reflects the latest process and detailed actions. In the *2021 Air Pollution Prevention and Reduction Action Plan*, Beijing sets air quality improvement targets for five priority areas: VOCs special management, vehicle structure enhancement, clean energy promotion, dust management improvement, and regional coordination. Detailed tasks, timelines, and responsible departments are listed in each action. For example, one of VOCs special management's tasks is strengthening the entire process monitoring on critical industries. To achieve this task, Beijing promoted the "One Factory, One Policy" system and identified 50 factories in the main sectors to improve management capacity and organize management evaluation in 2021. BEE leads the overarching effort, while district governments take primary responsibilities. BMCDR and BMBEIT also engage in this action as supporting departments (Beijing Municipal Government, 2021a).

4.1.2 Energy-related actions

4.1.2.1 Seoul

Household boilers are essential contributors to $PM_{2.5}$. SMG has been implementing an eco-friendly boiler replacement project since 2015 to replace old boilers with eco-friendly boilers that emit 88% less NO_x than regular boilers. SMG has supplied 480,000 eco-friendly boilers since the project launch. Under the revision of the *Special Act on the Improvement of Air Control*, it is mandatory for suppliers in Air Control Zones to install eco-friendly boilers since April 2020. Failing to do so will face punishment (SMG, 2022b).

Seoul plans to replace 1,450,000 old boilers used for more than ten years with eco-friendly boilers by 2024. SMG has implemented multiple policies to achieve this target. Firstly, SMG provides subsidies to households for eco-friendly boiler replacement. For households installing eco-friendly boilers that emit less than 20 ppm of NO_x and have more than 92% heat efficiency, the families can receive 200,000 KRW per boiler (2021 standards). In addition, the government provides more subsidies for low-income households who can receive KRW 600,000 for installing eco-friendly boilers. Secondly, SMG provides public information to help them better understand regular and eco-friendly boilers. As a result, the public can better under the advantages and disadvantages of traditional and eco-friendly boilers. Finally, SMG pays special attention to some targeted apartment complexes ready for replacement (SMG, 2022b).

4.1.2.2 Beijing

Replacing coal with clean energy and closing or relocating heavy industries have been critical strategies for Beijing to improve air quality. Beijing renovated and eliminated coal-fired boilers and achieved a coal-free city. The city completed the "coal-to-gas" and "coal-to-electricity" transition in 1.1 million households. From 2010 to 2019, the proportion of coal consumption in Beijing decreased

I Table 9. The process of renovating and eliminating coal-fired boilers in Beijing since 1998 (Source: UNEP, 2019)

Phase	Area	Focus	Implementation
I (1998-2002)	Core area[1]	Coal-fired boilers of less than 0.7 MW	10,633 coal-fired boilers involving 15,687 MW eliminated
II (2003-2008)	Core area	Coal-fired boilers of less than 14 MW	5,704 coal-fired boilers involving 15,499 MW eliminated
III (2009-2012)	Six urban districts[2]	Coal-fired boilers of 14 MW	598 coal-fired boilers involving 4,038 MW eliminated
IV (2013-2017)	Whole city area	Coal-fired boilers of 7 MW or less	8,312 coal-fired boilers involving 27,416 MW eliminated (not including 27,000 small domestic cookers)

Notes: 1. The core area refers to Dongcheng District and Xicheng District; 2. Dongcheng, Xicheng, Chaoyang, Haidian, Fengtai, and Shijingshan are the six urban districts.

sharply from 29.6% to 1.61%.

Since 1998, Beijing gradually closed coal-fired boilers in the city. Table 9 shows the progress of renovating and eliminating coal-fired boilers in the city, which first started at the core and densely populated areas due to air pollution concerns, and then gradually expanded to six urban districts and subsequently, the entire city. Aside from the spatial strategy, Beijing also began eliminating the small-size boilers of less than 0.7 MW and then moved to large-size boilers of 14 MW. As a result, by 2018, Beijing has achieved coal-free in all plain areas of the city.

Currently, coal consumption is mainly limited to the rural parts of Beijing; thus, the city focuses on coal reduction in rural areas. In 2021, Beijing aimed to complete the "coal-to-electricity" transition in around 18,000 households in 42 villages, further contributing to Beijing's air quality improvement.

4.1.3 Vehicle control

4.1.3.1 Seoul

Old vehicle restriction is the cornerstone to air pollution control by promoting eco-friendly driving culture, limiting vehicle-kilometers traveled, and emission-source control. Seoul initiated various policies in promoting a public-engaged driving culture to combat local air pollution, including eco-driving education, car-free day, car-free street, voluntary weekly-no-driving-day, eco-mileage, and attaching pollution control devices, as instituted in the "SMG ordinance on tackling climate change." Furthermore, the "One citizen, one ton less CO_2" training program encourages improved driving culture to limit vehicle idling and sudden acceleration. Furthermore, the In-Use Vehicle Emission Reduction project also massively installed low-emission devices like Diesel Particulate Filter (DPF) in 222,342 old diesel vehicles that met the attachment criteria, with SMG shouldering between 83% and 97% of the costs. Besides, the PM-Nox simultaneous-reduction devices have been piloted under the Nox Reduction Demonstration Project since 2013 (Seoul Solution, 2017), yielding successful results as annual NO_2 concentrations have been reduced to 0.02 μg/m^3.

Similar to the European concept of low emission zones (LEZs), SMG designated the inner area of the Seoul City Wall, including the neighborhoods in Jongno-gu and Jung-gu, as GTZ to fight against fine dust since March 2017. Within the GTZ, Grade 5 vehicles* will be limited, apart from emergency vehicles, people with reduced mobility, National Merit-awarded men, national special purpose vehicles, and vehicles installed with low emission devices.

4.1.3.2 Beijing

Beijing upgraded the transportation sector by eliminating outdated cars, promoting clean transportation approaches, and establishing low emission zones. Beijing banned all national III diesel trucks from entering the city, considering them outdated vehicles, starting from November 2019. In addition, Beijing is promoting two transport transformations: "road-to-train" and "fossil fuel-to-electricity." Beijing also advocates for the "road-to-train" transition by increasing the railway transportation for bulk materials, such as construction materials, commodity vehicles, and large deliveries. "Fossil fuel-to-electricity" transformation is supported by replacing conventional cars with electric and fuel cell vehicles for public sectors, such as public

* Grade 5 vehicles refer to small- and medium-sized diesel cars before July 2002 or a gas-powered vehicle made before 1987. For heavy duty vehicles, it refers to a diesel vehicle released before July 2002 and a gas-powered car before 2000

transport, sanitation, and other public services. By 2025, Beijing aims to reach two million new energy vehicles. Furthermore, Beijing updated the *Regulation on Pollution Prevention and Control from Motor Vehicles and Off-road Mobile Machines* and set low emission zones for off-road mobile machines. Beijing also started implementing the CHINA VI emission standards for light-duty vehicles and diesel-fueled heavy-duty vehicles in 2019.

4.1.4 Fugitive dust management

4.1.4.1 Seoul

To protect the public's health from fugitive dust and create a pleasant living environment, SMG implements intensive management on 11 major industries that are the main causes of fugitive dust, such as construction, fertilizer, feedstuff manufacturing, and cement.

Among them, the construction industry sector accounts for the majority (97.8%) of fugitive dust generation, and fugitive dust at construction sites contributes to 22% of total $PM_{2.5}$ (Seoul Institute, 2019); thus, SMG applies more robust fugitive dust control measures for construction sites.

I Table 10. $PM_{2.5}$ contribution ratio based on emission sources

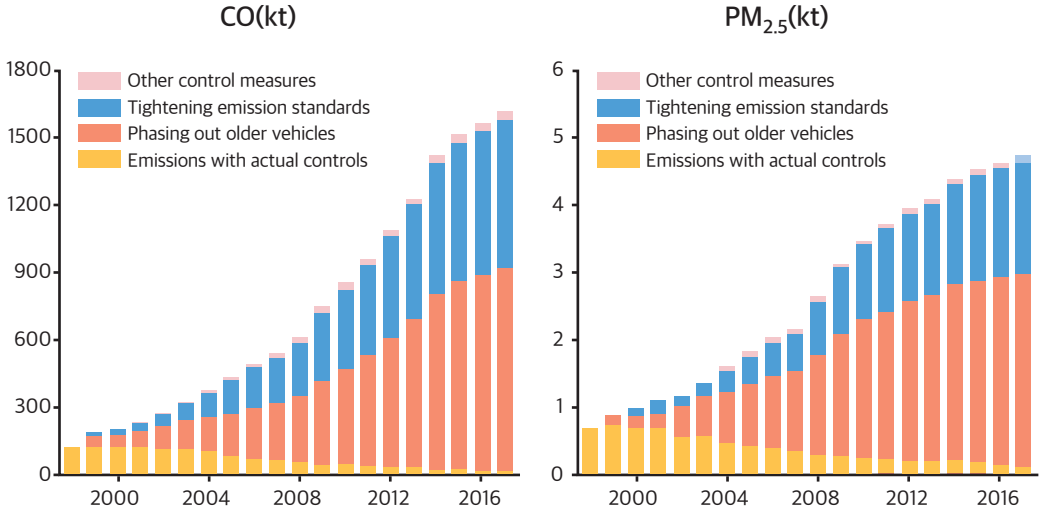
Total	Heating/ electricity	Automobile	Fugitive Dust	Construction Machinery	Others
100%	31	26	22	18	3

Twenty-three large construction sites (over 10,000 m^2) with large fugitive dust emissions have been designated eco-friendly construction sites, managed by stricter fugitive dust control standards than other construction sites. Specific measures include implementing a real-name system of construction vehicles, a clean-road responsibility management system, and the mandatory use of eco-friendly construction machinery. These measures will be extended to all large construction sites. In addition, SMG promotes an integrated fine dust control system using IoT technology to constantly monitor and immediately respond to fine dust generated at construction sites. The control system allows monitoring of fine dust in construction sites round-the-clock. There is also a plan in the pipeline to establish a real-time monitoring system to implement fugitive dust reduction measures immediately. The real-time notifications can lead to voluntary fugitive dust reduction at construction sites and contribute to a more pleasant living environment by responding directly to complaints.

SMG also regularly inspects control sites in autonomous districts and conducts special inspections to strengthen management and supervision of fugitive dust generation sites. In 2021, Seoul inspected 5,772 fugitive dust sites, of which 192 locations violated related regulations, and took measures such as suspension, enforced orders, and fines.

4.1.4.2 Beijing

Despite the threefold increase in automobile ownership growth in Beijing in the last two decades, the total pollutant emissions still decreased, most notably the CO, NOx, and $PM_{2.5}$ reduced by nearly 1,105 kt, 71 kt, and 6 kt in 2017 compared to 1988. Since most of the ambient $PM_{2.5}$ originates from motor vehicles (45%), construction dust (16%) and domestic source (12%), and industrial construction (12%), the city adopts an entire vehicle-fuel-road control system for motor vehicles. Phasing out older vehicles was considered one of the most effective



I Figure 21. Reduction effects of vehicular emission control in Beijing in 1998 – 2017 (Source: UNEP, 2019)

measures (UNEP, 2019). As a result, what is known as "co-management" between the city and the public has significantly reduced transport emissions in the last 20 years.

Furthermore, Beijing strengthened construction sites' monitoring and management as primary dust sources and increased the share of prefabricated buildings to 60% by 2025. Beijing also installed the smart video monitoring platform for construction dust, formulated control standards, and enhanced construction waste disposal capacity.

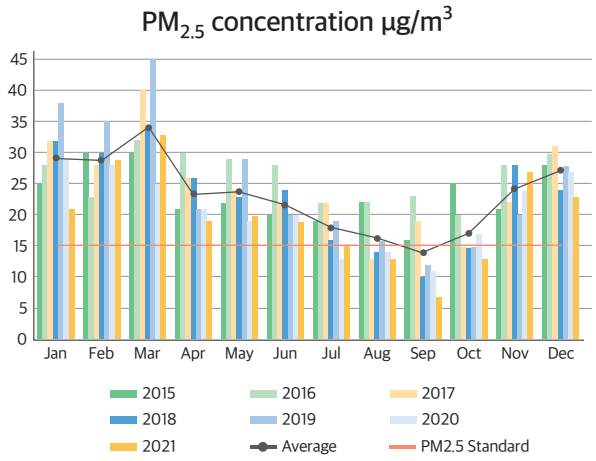
Beijing also released interventions to manage non-domestic dust sources, such as roads and bare ground. For example, Beijing improved the cleaning standards of urban streets and strengthened the dust residue M&E system. Beijing enhanced management capacity for barren farmland and land by promoting green covering. As a result, fugitive dust concentration per month was significantly reduced from 7.5 tons/km^2 in 2018 to 5.1 tons/km^2 in 2020.

4.1.5 Seasonal control

4.1.5.1 Seoul

Around 80% of the fine dust (PM_{10}) concentration exceedances (over 50㎍/㎥) occur between December and March. $PM_{2.5}$ ultra-fine dust concentration during these months is a tricky problem calling for stricter preventive and mitigation measures.

Since December 2019, Seoul has stepped up seasonal control measures to reduce emissions from transport, heating, and industrial activities to minimize exposure to air pollution. Nine key strategies and seven assistance measures have been identified in the first seasonal control, and 13 measures have been implemented in the second seasonal control. In the current third seasonal control, 16 measures are being implemented. Table 11 presents the main measures in the four main sectors, including transport, heating, and industry.



I Figure 22. Fine dust concentration across the months depicting the influence of seasonal fine dust (Data source: Clean Air Seoul)

I Table 11. Seasonal control measures in Seoul (Source: SMG, 2019b, 2019c, 2021e)

Areas	Strategies
Transport	• Ban vehicles with Grade 5 emission levels • Charge Grade 5 emission level cars with an extra 50% parking cost in municipal parking lots • Crackdown on the regulations of gas emissions and idling limit time of vehicles • Crackdown on gas emissions of vehicles on private automobile inspections • Implement special credit with vehicle mileage systems (award points to those who reduce driving distance)
Heating	• Supply eco-friendly boilers • Implementation of eco-mileage credits • Control on indoor temperatures of large buildings
Industry	• Inspect all businesses emitting air pollutants • Inspect industries emitting fugitive dust • Operate regular control system for emission sources • Prevent illegal incineration of agricultural wastes

4.1.5.2 Beijing

In Beijing, seasonal control actions are combined with regional coordination policies developed by the national government. The seasonal season policies in Beijing mainly target $PM_{2.5}$ in autumn and winter. To reduce $PM_{2.5}$ in autumn and winter, the Ministry of Ecology and Environment (MEE) released *the Comprehensive Air Pollution Action Plan for the Beijing-Tianjin-Hebei Region and Surrounding Areas and Fenwei Plain in the Autumn and Winter of 2020-2021*. Under the guidance of this regional plan, Beijing adopted a specific city plan covering energy, transport, land-use, heavy pollution responses, and capacity building. Beijing has also suffered from ozone pollution in recent years, especially in the summer. Beijing promotes the integrated management of $PM_{2.5}$ and O_3 by reducing VOCs. In the *Air Pollution Prevention and Control Action Plan 2021*, Beijing tailored a specific approach targeting VOCs, such as improving the VOC monitoring system, replacing conventional products with low-VOC content products, and strengthening the management of key sectors and areas (Beijing Municipal Government, 2021a).

4.2 Sectoral GHG emission reduction actions

4.2.1 Energy

ENERGY at a glance

	Seoul	Beijing
Key strategies		
	One Less Nuclear Power Plant Solar City, Seoul 2050 GHG Emissions Strategy Plan	The Beijing 13th FYP for Energy Development (2016-2020)
Energy mix (2020)		
Gas	30% (Natural gas and LPG)	37.16%
Oil	34.3%	29.27%
Coal	0.3%	1.5%
Electricity	29.6%	29.96%
Heat energy	3.6%	
New energy and renewable energy	2.2%	10.4%
Key energy figures (2020)		
	Solar energy: 305.3 MW Hydrogen: 141.7 MW	Solar energy: 510 MW Wind: 510 MW Biomass: 370 MW Heat pump application: 59.2 m^2

4.2.1.1 Seoul

Background

The energy sector is the city's largest GHG emitter, accounting for 91% of the total emissions in 2018. About 42.682 Mt CO_2eq was emitted from buildings, transportation, manufacturing, construction business, energy industry (power generation), and fugitive sources (Climate and Environment Headquarters, 2021a). Table 12 shows the GHG inventory of Seoul, showing its heavy reliance on energy consumption.

The three primary energy sources in Seoul are oil (40%), gas (Liquefied Natural Gas (LNG) and Liquefied Petroleum Gas (LPG), 30%), and imported electricity (29.6%) in 2020. As the most significant primary energy source, oil is mainly used for transportation, while gas is used primarily for residential and commercial building heating. Coal-fired energy accounts for 0.3% as the city uses electricity generated and transmitted from

I Table 12. The GHG emission distribution within the energy sector in Seoul in 2018 (Data source: Climate and Environment Headquarters, 2021b)

Total				100% (47.073 Mt CO_2eq)
Energy	Sub-total			90.7%
	demand	Sub-total		92.2%
		Buildings	Sub-total	68.80%
			Residential buildings	27.90%
			Commercial buildings	37.10%
			Public buildings	3.80%
			Agriculture and Fishery buildings	0%
		Transportation		19.20%
		Manufacturing and Construction Industry		2.50%
		Energy Industry		1.40%
		Fugitive Emissions		0.20%
	Supply	Sub-total		-1.5%
		Electricity		-0.6%
		Heat		-0.9%

I Table 13. Key energy policies

	National policies	Seoul
Main Policies	• The Third Energy Master Plan (2019-2040)	• The Fifth Seoul Energy Master Plan (2020-2040) • One Less Nuclear Power Plant (2012-2020)
Renewable Energy	• The Fifth Basic Plan on Renewable Energy (2020-2034) Hydrogen Economy Roadmap	• Solar City • Seoul Climate Action Plan
Electricity	• The Ninth Basic Plan for Power Supply and Demand	

power plants in provincial cities and towns (Climate and Environment Headquarters, 2020). Considering the three primary energy sources, the energy supply of Seoul is highly dependent on imported energy from overseas and the surrounding provinces.

After meeting the peak load (amounting to 16,008 ktoe (thousand tons of oil equivalent)) in 2007, the city's energy demand has shown a decreasing trend with 13,316 ktoe in 2020. Nonetheless, the upward energy consumption trend is due to an inevitable consequence of urban development and population growth. In 2020, Seoul's energy demand made up 6.0% of the national total energy demand. Seoul's energy challenge is two-fold: high-level dependence on external energy sources; and high energy demand and consumption. Therefore, SMG initiates a transition to clean and sustainable energy by expanding renewable power systems and maximizing energy efficiency with the Information and Communications Technology (ICT) and Industry 4.0 innovative technology (Climate and Environment Headquarters, 2020, 2021c, 2021d).

Key actions

Energy supply

Solar energy

Solar energy is favored as renewable energy as the solar panels occupy less urban space and are free of particulate matter. Furthermore, the distributed nature of solar panels contributes to energy independence and decentralization (Climate and Environment Headquarters, 2020; SMG, n.d.e). Therefore, SMG promotes the expansion of solar energy in terms of the sustainable energy transition, given the advantages of installing solar panels and the urban environment. SMG has put efforts into enhancing energy self-sufficiency and reducing GHG emissions through two initiatives designed to promote solar energy - the One Less Nuclear Power Plant and the Solar City, Seoul (Climate and Environment Headquarters, 2017; SMG, n.d.c, n.d.d).

SMG adopts two approaches to expand solar energy. First, in terms of deploying solar power generators, SMG encourages public engagement in deploying small-sized solar power generators to housing units and installs various places depending on housing types. The installation of BIPV is specially promoted to expand solar energy and improve the urban landscape. SMG encourages the public sector to take the lead in deploying solar power generators and installing the generators at available public buildings and sites. SMG plans to utilize public and private partnership and regulatory reform and construct solar energy landmarks to raise public awareness on the expansion of solar energy across the city (Climate and Environment Headquarters, 2017). In advancing and demonstrating innovative technology, SMG will set up a district specialized in solar energy and use it as a testbed for developing a smart energy city model. For instance, a testbed has been set up (2020~onwards) in the Seoul Energy Corporation to demonstrate 15 technologies such as colored BIPV, BIPV, solar roadways, solar soundproof walls. SMG further built a cooperative relationship with six agencies to develop a model for comprehensive support from technology demonstration to market development. Besides, SMG will create an ecosystem for the solar energy industry (Climate and Environment Headquarters, 2017; SMG, 2021d).

Implementation of Phase 1 and 2 of the One Less Nuclear Power Plant initiative resulted in saving 6.87 million toe of energy between April 2012 and December 2020, exceeding the initial expectations. Meanwhile, the solar energy capacity also significantly increased to 305.3 MW from 22.6 MW between 2011 and 2020, which the Solar City also supports. As a result, the self-sufficiency of the city's electricity system drastically improved from a meager 3% to 13.9% (Climate and Environment Headquarters, 2020; SMG, n.d.c). SMG expects the city to benefit from the growth of solar energy to enhance self-sufficiency in electricity, reduce GHG emissions, and improve air quality. Meanwhile, adding to the policies implemented so far, SMG has been consistently implementing solar power supply by turning its focus to efficient strategies, including new technology and high efficiency.

Hydrogen fuel cells and other energy sources

In addition to solar energy, SMG identified hydrogen fuel cells as another primary distributed energy source given urban conditions and needs.

Considering urban needs and conditions, SMG designated hydrogen fuel cells as its major distributed power source with solar power. Hydrogen fuel cells generate energy as they produce heat and electricity simultaneously and emit water (water vapor) through chemical bonds between hydrogen and oxygen. They can also generate electricity 24 hours a day regardless of the environment. However, the only way to produce hydrogen from the city is to reform city gasses, generating CO_2. Nonetheless, hydrogen fuel cells are suitable for facilities with base power in the city because there is no emission of air pollutants or fine dust, unlike thermal power generation. Thus, SMG attracts power generation facilities in unused spaces of urban infrastructure and expands the installation through mandatory installation in new medium and large buildings. As of 2020, it is reported that 11 hydrogen fuel cells (134.1MW capacity), 338 hydrogen cells (7.2MW capacity) are installed in buildings, and 433 hydrogen cells (0.4MW capacity) are installed in houses (Seoul, 2021a).

Although hydrogen fuel cell installation and operation challenges arise, such as expensive cost and use of city gas, SMG demonstrated a strong political will to facilitate its promotion. SMG recently published the 2050 Seoul Climate Action Plan and envisions the feasibility of hydrogen fuel cells as part of the strategy to achieve carbon neutrality by 2050. SMG targets to deploy 200MW of the hydrogen fuel cell by 2022 and 1GW of the hydrogen fuel cell by 2050. SMG will carry out regulatory reform to increase hydrogen fuel cells' economic value and social acceptability. Then, medium- and large-sized buildings will use hydrogen fuel cells as an emergency power generator instead of diesel. Hydrogen fuel cells installed in buildings will be used for the electricity trade, and residents will receive benefits in return for their consent to establish plants for hydrogen fuel cells (Climate and Environment Headquarters, 2021a, 2021c).

Besides, SMG makes efforts to diversify renewable energy sources, such as water, heat from waste incineration, bioenergy, and wind. Despite the many small-scale energy generations based on these resources compared to solar energy and hydrogen fuel cells, SMG seeks opportunities to deploy the power generators. For example, Climate Change White Paper published by SMG highlighted the potential of hydroelectric power. Seoul city operates four small hydropower generators with a capacity to produce up to 456 kWh with water's kinetic and potential energy. Advanced technology for the low head has been developed and applied to a hydroelectric power plant less than two meters high. While implementing installment of generators at Jamsil

submerged weir to use Han River, SMG sets a target for completing 2,500 kW facility capacity in 2023.

Energy efficiency

Energy efficiency is another crucial pillar for transformation into a sustainable energy system in Seoul. Community energy is a classic example of a partnership approach to enhance energy efficiency and decentralize the energy systems in metropolitan cities. SMG has promoted community energy since the 1980s in terms of heat and electricity from the operation of energy plants provided to communities in the residential, commercial, and industrial areas, which provided eco-friendly heating to 257,000 houses in Seoul in 2020 District heating is expanded by utilizing various energy resources, such as waste heat from the fuel cell and resource recovery facilities and latent heat from sewage water in neighboring city areas (SMG, 2021a).

Along with community energy, SMG also makes efforts to maximize energy efficiency in data center management. For example, Seoul transformed a data center, which is a large electricity consumer, into a Green Data Center. SMG applied green IT and operated multiple virtual servers through sharing the Central Processing Unit (CPU), memory, and disk of one physical server. As a result, between 2014 and 2019, the city operates 483 virtual servers, saving 2,117,680 kWh of energy. SMG further saved energy by maintaining constant temperature and humidity in 2019 (SMG, 2020a).

Moreover, SMG adopts measures to enhance energy efficiency by replacing old equipment with eco-friendly equipment. SMG deploys eco-friendly equipment on streets, including LED signboards, LED security lights, LED streetlights. For example, in 2019, SMG replaced 8,892 lights on streets and used less energy than before. Installation of energy-efficient and eco-friendly equipment led to less energy use, less GHG emissions (1,482 tCO_2 less emitted), and alleviated light pollution in the city (SMG, 2020a).

SMG expanded energy efficiency measures and further transformed the city into a smart energy city through advancing energy management, carried out through energy monitoring, energy data visualization, and energy use management. Also, the city will encourage the provision of the energy efficiency service led by the private sector through simulating future energy supply and demand and using an open Application Programming Interface (API). Furthermore, developing and demonstrating models of the smart energy city will continue to 2023 through several measures (Climate and Environment Headquarters, 2021c):

- introducing electricity rates based on electricity usage
- engaging local communities in trading renewable energy generated in local areas
- establishing and operating community power plants, and
- adopting Demand-Response (DR) regulations

Barriers and challenges

The biggest challenge of the Seoul metropolitan in the energy sector is high energy demand, representing 10.3% of the national total energy use while generating only 3% of the electricity demand and renewable energy accounting for merely 1.6% of energy demand (Korea Electric Power Corporation, 2020). Therefore, Seoul set an ambitious target to transform into a sustainable energy system and enhance energy self-sufficiency. For instance, Seoul aims to increase renewable energy share by up to 17% and electricity independence up to 35% by 2040 (Seoul Institute, 2020). SMG addresses both energy supply and energy efficiency in the energy system transformation. However, constraints on the energy supply (e.g., space limits, a lack of diversity, low energy density, and intermittent renewable energy production) remain the main barriers to enhancing energy self-sufficiency.

Another challenge in the energy sector is the establishment of energy distribution infrastructure. For example, Seoul city promotes solar panel installation to accelerate distributed energy generation. In this regard, SMG implemented two One Less Nuclear Power Plant phases. The first phase of the initiative resulted in the significant increase of solar power stations to 3,762, saving 2.04 million toe energy consumption (Climate and Environment Headquarters, 2015; SMG, n.d.d). In parallel with the second phase of the initiative, SMG has implemented 'Solar City, Seoul' since 2017 with the target of 1 GW solar energy production by 2022, which was later adjusted to 500 MW taking into account the current situation of the solar panel supply (Financial News, 2021). Another challenge arises from a lack of infrastructure accommodating renewable energy. If solar energy generation is disconnected from grids, the interconnected network between producers and consumers and energy loss lead to energy inefficiency (KukminIlbo, 2021). For example, Jeju Island experienced energy loss and inefficiency. The island shut down wind power stations due to overproduced energy. Therefore,

different strategies to secure infrastructure, including transmission lines, substations, Energy Storage Systems (ESS), and Power-to-Gas (P2G), need to be developed to maximize the efficiency and effectiveness of sustainable energy transition (Electric Power Journal, 2020).

Lessons learned

SMG has developed various approaches to sustainable energy transition from energy generation, energy efficiency and conservation, and citizen engagement perspectives. SMG sets directions for the energy transition to strengthen energy independence through efficient energy use and deployment of renewable energy power stations. SMG also lays the foundation for promoting the transition by providing the administrative, regulatory, and financial frameworks.

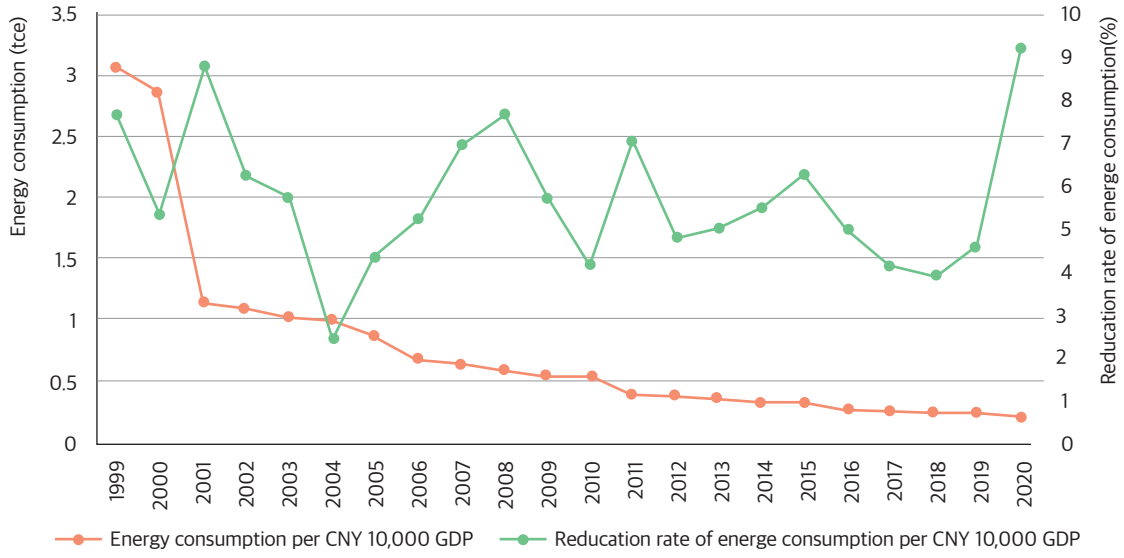
Public engagement has been the core of Seoul's energy transition. Considering the high energy consumption and limits of the urban environmental conditions, public participation in energy generation serves as an engine to change public behavior and achieve the city's energy target. Moreover, as an energy-sharing community, the public plays an active role as energy prosumers - producing and consuming energy - beyond a traditional role in simply using power. Although this ambitious initiative is still under development, it implies the importance of decentralized energy generation as a solution to lower dependence on external energy resources. This excellent model can be transferred to other metropolitan cities.

4.2.1.2 Beijing

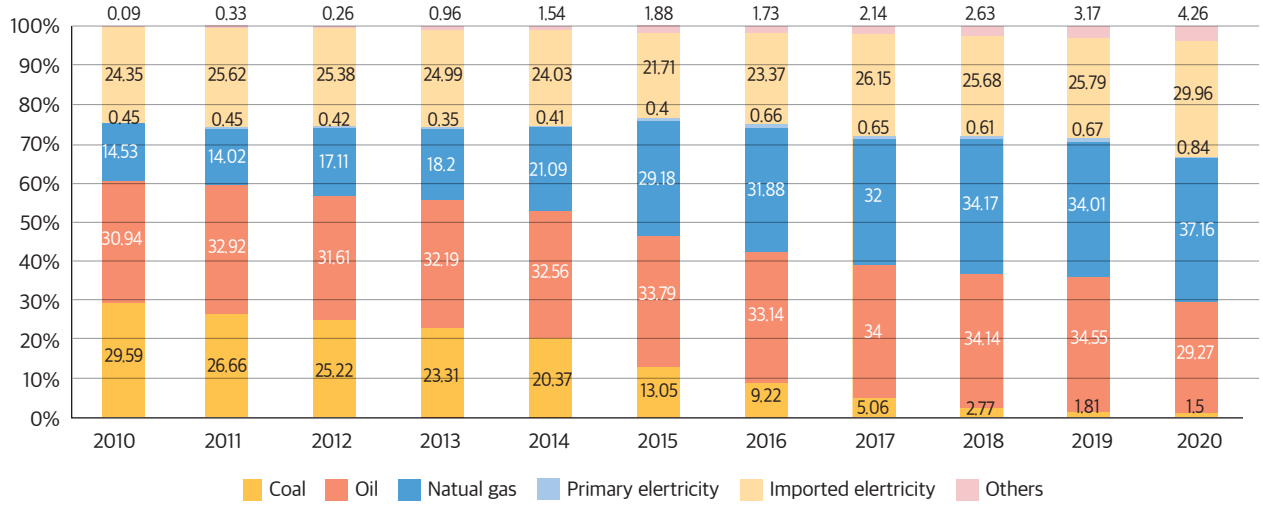
Background

In recent decades, Beijing has significantly reduced the energy intensity of economic activities while maintaining strong economic growth. Although Beijing's economic growth slowed down in the recent five years, the GDP growth rate is still maintained above 6%. Meanwhile, the energy efficiency of economic activities has also been increasing. Figure 23 shows that the primary energy consumption per CNY 10,000 GDP reduced from 3.03 metric tons of coal equivalent (tce) in 1999 to 0.21 tce in 2020, decreasing by over 93%. From 1999 to 2020, the primary energy consumption per CNY 10,000 GDP was reduced by an average of 5.66% per year.

The significant increase in energy efficiency was primarily attributed to the energy structure transformation, as shown in Figure 24. From 2010 to 2020, the most impactful achievement of the energy structure transformation is that Beijing has almost eliminated coal use, as coal consumption decreased sharply from 29.59% to 1.5%. Meanwhile, natural gas plays an increasingly important role in replacing coal, doubling from 14.58% to 37.16%, as Beijing's most significant energy source. Besides natural gas, oil and imported electricity constitute a substantial part of Beijing's energy mix. The share of oil steadily increased from 30.94% in 2010 to 29.27% in 2020. Electricity imported from other regions comprises 29.96% of the total energy consumption. Beijing has put additional effort into importing electricity generated by renewable energy in surrounding regions among the imported electricity.



I Figure 23. The evolution of energy consumption per CNY 10,000 GDP in Beijing from 1999 to 2020 (Data source: Beijing Municipal Bureau of Statistics, 2022)



I Figure 24. Primary energy consumption structure in Beijing from 2010 to 2020 (Data source: Beijing Municipal Bureau of Statistics, 2022)

Beijing has made noteworthy achievements in energy development. Firstly, Beijing successfully maintains rapid economic growth while controlling the total energy consumption through the significant increase in energy efficiency. Secondly, Beijing significantly curtailed coal consumption by replacing it with natural gas, a cleaner and more efficient fuel that emit fewer air pollutants and CO_2 than coal. The coal production and consumption phase-out was a critical part of Beijing's air pollution battle for clean air and blue skies. Thirdly, non-fossil fuel use in Beijing increased steadily, which contributed to controlling GHG emissions. These laid a strong foundation for Beijing's push to achieve carbon neutrality and to further transform its energy system from fossil fuel-centered to non-fossil fuel-centered.

The following sections explain in detail how Beijing transformed the energy system. In terms of energy supply, Beijing phased out coal. From the energy consumption perspective, Beijing strengthened the industrial structure and improved energy efficiency.

I Table 14. Key energy policies

	National policies	Beijing
Main policies	The Energy Development Strategy Action Plan (2014-2020) The 13th FYP for Energy Development (2016-2020)	The Beijing 13th FYP for Energy Development (2016-2020)
Fossil fuel control	The Coal-fired Power Energy Conservation and Emission Reduction Upgrade and Transformation Action Plan (2014-2020)	The Beijing 13th FYP for Gas Construction (2016-2020)
Renewable energy	The 13th FYP for Renewable Energy Development (2016-2020)	The 13th FYP for New Energy and Renewable Energy Development (2016-2020)
Energy efficiency		The Pilot Implementation Plan for Energy Efficiency Leaders (2016-2020) Notice on Conducting Energy Conservation Supervision Work in 2020

Key actions

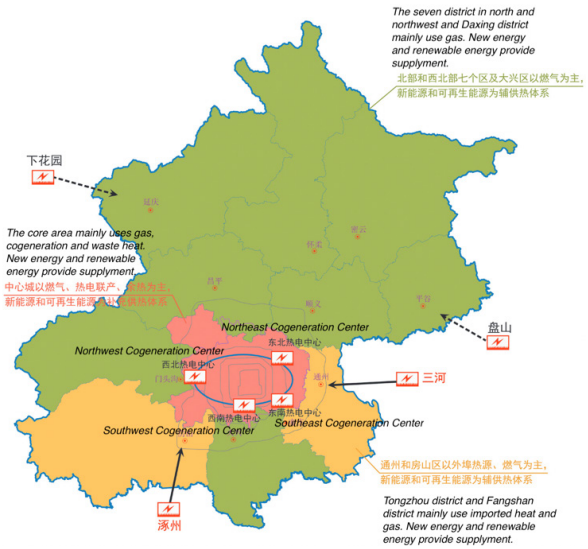
Coal-to-clean energy transition[*]

Beijing strives to achieve a coal-free city through strong coal-to-clean energy transition policies. Beijing aims to develop an energy supply system that incorporates "multiple energy sources, multiple directions, and multiple points." Beijing's strategy is to "reduce coal, strengthen natural gas and electricity, and improve renewable energy" to secure multiple energy sources. In this direction, Beijing has been expanding natural gas and imported electricity to replace coal and introducing renewable energy. This transition started in the urban areas and then expanded to rural areas in 2016.

Coal-to-Natural Gas

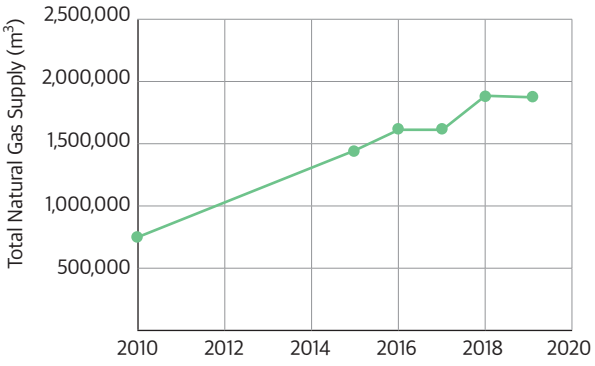
* Since natural gas has higher energy efficiency and emits less air pollutants and CO_2 than coal, it is considered as clean energy in Beijing's policy designing.

From 2014 to 2017, Beijing constructed four natural gas cogeneration centers. Figure 25 shows the locations of the four centers, which serve as the main power and heating sources for the core area in Beijing. The four centers increased the electricity generation capacity by 7.24 million kW and heating capacity by 100 million m^2, accounting for 50% of the significant concentrated heating network. Compared to the coal-fired power plants, the four centers reduced coal consumption by around 3 million tons, leading to SO_2, NO_x, and dust emission reduction of 10,000 tons, 19,000 tons, and 3,000 tons, respectively. By 2019, the power sector became almost coal-free as the gas-fired plants generated most power.



I Figure 25. The heat system in Beijing (Source: Beijing Municipal Government, 2016; translated by the Author)

Because of the enormous investment in natural gas infrastructure and substantial subsidies, Beijing's total natural gas supply increased significantly (Figure 26), which played a crucial role in reducing coal consumption.



I Figure 26. Total natural gas supply in Beijing from 2010 to 2019 (Data source: China National Bureau of Statistics, 2021)

According to estimation, replacing coal with natural gas reduced air pollution by 90% or more and CO_2 emission by around 50%, provided that the natural gas does not leak (Sandalow, 2019). Therefore, at least in the near term, the coal-to-natural gas transition will continue to support Beijing's effort to control CO_2 emissions and improve energy efficiency.

During the 14th FYP period, Beijing plans to control the scale of natural gas use. Beijing will increase green power import and reduce the proportion of local gas-fired units for power generation. Beijing will also strictly control new independent gas heating systems and promote integrated heating systems, such as electricity and solar energy. By 2025, Beijing aims to peak its natural gas consumption and control the usage at about 20 billion m^3 (Beijing Municipal Government, 2021d).

Coal-to-Electricity (Electrification)*

In addition to promoting natural gas, Beijing also built new local power plants and imports power from surrounding regions to replace coal.

Beijing developed the local power generation system incorporating four cogeneration centers, district energy centers, and renewable energy power stations. The four gas-fired cogeneration centers (shown in Figure 25) function as a foundation for Beijing's local power supply. District energy center projects in the Tongzhou Canal core and northern Haidian areas are essential power generation plants in non-core areas. In addition, renewable energy plays a supportive role in Beijing's local power generation system.

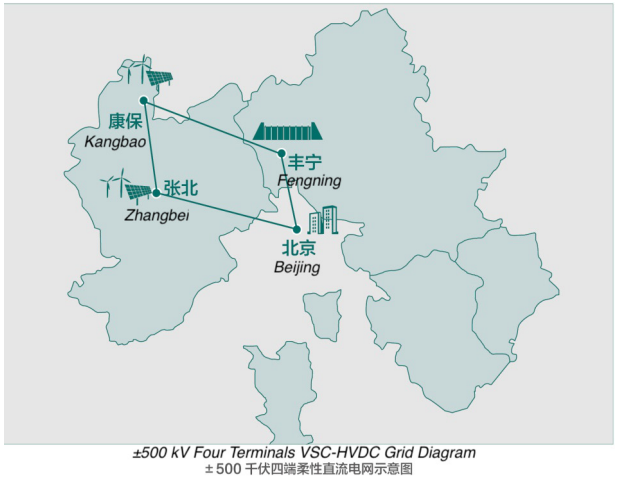
Because of the local resource limit in Beijing, the city implements a strategy of importing electricity from surrounding regions to improve the power supply. As Figure 24 shows, imported electricity contributed to 25.79% of Beijing's primary energy consumption in 2019, much higher than local power generation.

Beijing strengthens power grids to improve power import capacity. Beijing has been building grids that connect Beijing with the surrounding regions' power systems. Under the national *West-Power-to-East* and *North-Power-to-South* power transmission strategies, Beijing has completed Weixian-Mentougou (Beijing) and Zhangnan-Changping (Beijing) third loop 500kV power transmission projects.

In addition to deploying renewable energy within the city, Beijing imports green power generated

* In China's context, coal-to-electricity transition means promoting electrification without power generated by coal.

by renewable energy to support renewable energy development. Beijing aims to import 30 billion kWh of green power by 2025. In addition, Beijing works with the surrounding provinces to promote the construction of renewable energy bases, build Beijing-Hebei-Shanxi-Inner Mongolia green power channels, and cultivate a market for coordinated renewable energy development. The Zhangbei Renewable Energy VSC-HVDC (the Voltage Source Converter-High Voltage Direct Current) Project is a flagship project. With the most advanced transmission technology, the project supplies power generated by PV and wind turbines in Zhangbei and Kangbao and pumped-storage hydroelectricity in Fengning to Beijing, which significantly improves Beijing's capacity for importing and using regional renewable energy resources.



I Figure 27. The schematic diagram of the Zhangbei Renewable Energy VSC-HVDC Project (Source: China Solar Thermal Alliance, 2020; translated by the author)

Subsidies for coal reduction

To support the coal-to-clean energy transition, Beijing provided subsidies for clean energy renovation of coal-fired boilers, coal-to-electricity heating transition for urban bungalows, and bulk coal management in the rural areas. For example, for coal-to-electric heating renovation, urban households received subsidies that covered two-thirds of the cost of an electric heater and bill discounts that could reduce a maximum of 78% of the heating electricity tariff (UNEP, 2019). These subsidies have the potential to reduce customers' financial burden to upgrade their coal-fired equipment.

Renewable energy promotion

Given the scale of natural resources in the city, Beijing's renewable energy development strategy focuses on solar energy and geothermal, meanwhile advancing wind energy and biomass. Beijing released the Notice on Further Supporting the Promotion and Application of Photovoltaic Power Generation Systems to promote solar energy development. Table 15 shows the Six Sunshine Project included in the notice. The government provides various incentives for stakeholders to uptake PVs. For example, the government requires public-funded projects to prioritize solar PV applications. The municipal government also encourages district governments to provide support based on their local context and market entities to adopt various forms (e.g., independent investment or energy contract management methods) to construct and operate distributed PV projects. Among all incentives, a key motivation is financial subsidies for

I Table 15. The Six Sunshine Project in Beijing (Adapted from BMCDR, 2020)

Key areas	Details
Sunshine House	• Encourage residents to install distributed PV generation systems on the house roofs
Sunshine Industry	• Install distributed PV generation systems at new buildings in critical industrial areas, such as Winter Olympics areas • Encourage to install PVs in featured towns and plants, especially in industrial parks in Yizhuang and Shunyi • Encourage to install of PVs on the roofs of existing factories and logistics warehouses
Sunshine Business	• Install distributed PVs at large shopping malls, supermarkets, and office buildings • Promote green consumption behavior
Sunshine Countryside	• Install PVs in village houses • Install distributed PV generation systems at agriculture facilities
Sunshine Infrastructure	• Install distributed PV power generation systems in infrastructure, such as rail transit stations and sewage treatment plants • Study and promote the use of unused lands, such as closed mines, to build PV power plants
Sunshine Public Institute	• Install distributed PVs in newly built schools, hospitals, and government office buildings • Transform to PV power generation systems in the centralized office areas of municipality and district governments • Prioritize PVs for government-invested projects

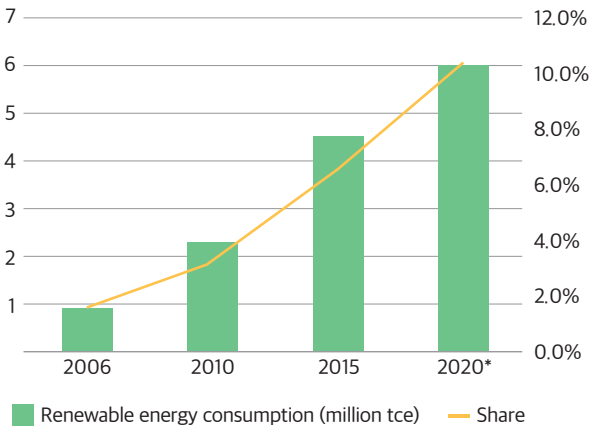
I Table 16. Subsidies for distributed PVs users in Beijing (Adapted from BMCDR, 2020)

Project types	Subsidy criteria (CNY/kWh)
General industrial and commercial areas, large industrial areas, and agricultural areas	0.3
Household PV generation project on self-owned houses for personal use	0.3
Non-resident user projects are eligible for residential electricity prices, such as schools and social welfare centers.	0.4
High-end projects, such as building-integrated photovoltaics (BIPV)	0.4

distributed PVs users, which last five years for each project, as shown in Table 16.

Beijing develops geothermal energy for heat supply. To achieve a clean heating transition in rural areas, the government promotes heat pumps to replace coal-fired boilers. Beijing uses heat pumps to provide heating and cooling in new development zones, such as the city's sub-center and the Beijing New Airport Economic Zone. In the areas surrounding the power plants in Dongba and Jinzhan Park, heat pumps are applied to utilize waste heat, while the reclaimed water trunk lines of Shougang and Lize areas use water-source heat pumps. In 2020, the size of the heat pump application in Beijing reached 59.2 million m^2.

The above policies have supported renewable energy development in Beijing. According to estimation, the use of new energy and renewable energy exceeded 6 million tce and accounted for 10.4% of primary energy consumption in 2020, which increased from 0.9 million tce and 1.5% in 2006 (Figure 28). In 2020, the installed capacity of solar panels reached 510 MW, accounting for almost half of Beijing's renewable energy capacity. In addition, the installed biomass and wind energy capacity was 370 MW and 190 MW, respectively. Meanwhile, the



I Figure 28. Renewable energy development in Beijing (Data source: BMCDR, 2016, 2021)

* The data of 2020 were estimated and not included in official statistics yet.

scale of heat pump development and utilization reached 59.2 million m^2. In summary, Beijing has increased the use of renewable energy in the past decade.

Energy efficiency

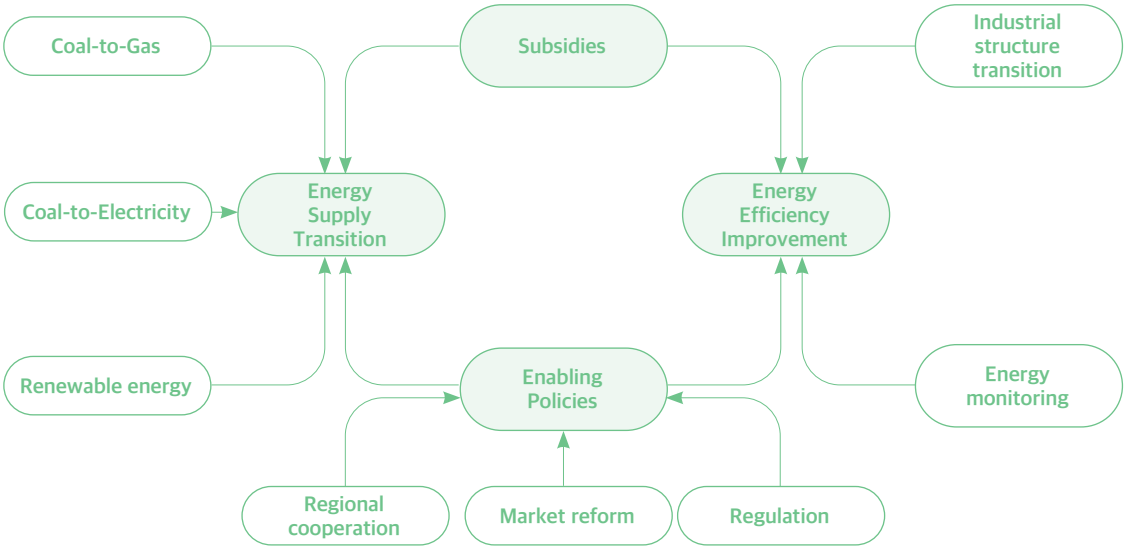
Beijing has been improving the heating system's energy efficiency and large energy consumers, such as data centers. For example, Beijing improved the efficiency level of the energy system, promoted household heating metering, and continued to reduce energy consumption for heating. Beijing also promoted efficient energy use of data centers and took the lead in advancing the energy-saving transformation of existing small data centers of government agencies and public institutions.

Beijing also strengthened the energy consumption monitoring system to encourage critical energy consumers to improve energy efficiency. The *Beijing Municipal Energy Conservation Supervision Team* conducts energy monitoring work on (1) key energy consumption entities with an annual energy consumption of 5,000 tce or more; (2) fixed-asset investment projects subject to energy conservation review; (3) energy conservation service agencies; and (4) entities included in the clean production audit list.

In the long term, Beijing plans to develop a green energy system based on the above actions. Beijing will strictly control fossil fuel consumption and improve energy efficiency. By 2035, Beijing aims to control the total energy consumption under 90 million tce and at around 85 million tce. Beijing also aims to improve new energy and renewable energy proportion to approximately 35%.

Barriers and challenges

Beijing needs to reduce fossil fuel consumption in the city further, although significant progress has been made to eliminate coal production with gas power plants and renewable energy. While the gas power plants serve as an excellent mid-term transitional solution, they are expected to be in service for a long time, which means



I Figure 29. Energy policy framework in Beijing

the anticipated GHG emissions of these power plants cannot be ignored. Beijing also released plans to control natural gas consumption. Another solution to reduce emissions from the gas power plants is installing carbon capture and storage (CCS) technology, but technological breakthrough is needed.

Beijing has significant potential to improve renewable energy development representing around 10% of the energy mix in 2020, and the majority is from solar energy. Beijing imports considerable green power from outside of the city. Therefore, there is a need for the city to work to increase renewable energy supply from outside the region and strengthen the distribution network as well as increase sufficiency in local clean energy generation. Furthermore, it is essential to achieve technology breakthroughs and enhance cooperation with other regions where renewable energy is abundant. Technology innovation market-based policies, followed by reducing the energy intensity of the economic structure, are essential for Beijing to achieve the carbon neutrality targets in the mid-and long-term.

Lessons learned

The energy sector development has contributed significantly to reducing energy intensity and air pollution in Beijing through solid political support and alternative energy infrastructure, i.e., the gas and electricity facilities. Regional cooperation in importing power, especially renewable energy, plays a vital role in the coal-to-clean energy transition. As a result, Beijing quickly improved renewable energy to around 10% in the energy mix. Government-invested pilot projects and subsidies for various renewable stakeholders attribute to the significant growth of renewable energy. For example, the Six Sunshine Project identified priority areas, provided subsidies, and promoted public engagement for solar energy development. From the energy consumption perspective, Beijing has been strengthening energy monitoring to improve the energy efficiency of large energy consumers. Figure 29 shows the critical energy policies adopted by Beijing.

4.2.2 Building

For metropolises like Seoul and Beijing, the building sector accounts for enormous energy consumption, leading to substantial GHG emissions. Reducing GHG emissions from the building sector requires energy efficiency improvement at the consumption end and renewable energy promotion at the supply end. Under the two directions, Seoul and Beijing have adopted multiple policies, including old building renovation, energy-efficient building promotion*, building energy consumption monitoring, and building energy efficiency standard setting.

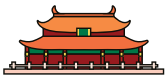
This report focuses on the GHG emissions generated at the building operational stage because it is the most energy-intensive stage compared to the building construction and decommissioning phases. Energy is required for heating, cooling, light, and powering other daily activities.

GHG emissions from building operation activities can

* The two cities promoted different types of energy efficient buildings to guide the development of new buildings. The types of energy efficient buildings mentioned in this report include the Zero Energy Building, the Green Building, and the Prefabricated Buildings.

BUILDING at a glance

Seoul



Beijing

Key strategies

	Seoul	Beijing
	Green Retrofitting Zero Energy Building Initiative	The 13th Five-Year Plan for Energy Conservation Development of Civil Buildings (2016-2020)

Building statistics

	Seoul	Beijing
Total building area[1]	557 million m^2 (2018)	805.7 million m^2 (2015)
Residential buildings occupied area	52.8%	60.7%,
Commercial building occupied area	31%	39.3%[2]
Energy consumption share of the city's total final energy consumption	63% (in 2018)	45.6% (in 2014)

Notes:

1. Seoul published the data of Gross Floor Area (GFA), while Beijing published data on the total area of civil construction in urban territories.

2. The data represents the share of public buildings, including government-owned and commercial buildings, in Beijing.

be divided into direct and indirect emissions based on the emission source. Direct emissions happen within the buildings, such as burning coal or gas for cooking and heating. Replacing conventional fossil fuel-powered facilities with electric facilities (i.e., electrification) can reduce direct emissions. Indirect emissions occur outside the buildings but result from consumption activities inside the buildings, such as consuming electricity or heat generated in stations powered by fossil fuels. Reducing indirect emissions requires replacing fossil fuels with low carbon energies and improving energy efficiency within buildings.

Tackling indirect emissions usually leads to a higher impact than reducing direct emissions. According to estimation, the building sector in China leads to around 600 Mt CO_2 of direct emissions, while indirect emissions contribute to about 1,550 Mt CO_2 and account for 16% of China's total CO_2 emissions (THUBERC, 2021). To reduce direct emissions, cost-effective alternatives are already available to replace conventional facilities. Therefore, reducing indirect emissions becomes the priority to achieving a low carbon building sector compared to direct emissions.

Building type and age are other vital factors that affect GHG emissions from buildings. Buildings can be divided into residential, commercial, and public buildings, categorized according to the building function and usage. In general, commercial and public facilities are more energy-intensive than residential buildings. Similarly, old buildings usually have lower energy efficiency due to outdated building standards and technology.

4.2.2.1 Seoul

Background

Seoul metropolitan is home to about 10 million residents. According to the Seoul Institute report, there were 604,726 buildings in the city in 2018. About 75.2% of the buildings were classified as residential, occupying 52.8% of urban areas. When combining commercial buildings and residential buildings, the buildings accounted for 96.2% of the total number and 83.8% of the entire areas occupied by buildings. Detached houses are the most common building type, while housing complexes occupy the most significant area (J. Yoo & C. Yoon, 2020).

Buildings have an important implication on energy use. In 2018, buildings in Seoul city accounted for 63% of the total final energy consumption of the city, in which commercial buildings accounted for 35.6%, and residential buildings accounted for 21.9%. Public buildings had the most effective energy use per unit

area, followed by commercial establishments (J. Yoo & C. Yoon, 2020). The considerable energy consumption means that buildings also have an important implication to GHG emissions. In 2018, buildings emitted about 32.4 Mt of CO_2eq and accounted for 68.8% of the city's total emissions, the largest share of GHG emissions (Climate and Environment Headquarters, 2021b).

Table 17. The share of GHG emissions by building types in Seoul (Data source: Climate and Environment Headquarters, 2021b)

Sub-total	68.80%
Residential buildings	27.90%
Commercial buildings	37.10%
Public buildings	3.80%

Compared to the 2005 level, the emissions of private and public buildings increased by 16.7% and 13.2%, respectively, while the emission of residential buildings showed a decrease of 10.9% (Climate and Environment Headquarters, 2021b; Metro Seoul, 2021). In general, the emissions from buildings showed an upward tendency due to the rising Gross Floor Area (GFA) from 479 million m^2 in 2005 to 557 million m^2 in 2018 (Climate and Environment Headquarters, 2021d). Therefore, SMG has developed plans to lower GHG emissions from the building sector by minimizing energy use and maximizing energy efficiency. In addition, detailed strategies were developed, considering building types.

When developing detailed strategies for buildings in terms of demonstration projects, finance, and mandatory regulations, SMG applies several criteria of buildings, such as construction years, use, and owner. With the criteria for the construction year, buildings are primarily grouped into old buildings and newly built buildings. With the requirements for use, buildings are mainly categorized into residential and commercial buildings. Finally, with the criteria for owners, buildings are primarily grouped into public buildings and private buildings. Therefore, this subchapter also looks into the strategic details of buildings, such as old and new, public and private buildings.

Table 18. Key building policies

	National policies	Seoul
Old buildings	Green Remodeling Project	Green Remodeling Project Building Retrofit Project for private buildings
New buildings	Zero Energy Building (ZEB) Mandatory Regulations	Zero Energy Building (ZEB) Mandatory Regulations
Others	Building Energy Big Data	GHG Emissions Cap Energy Performance Certification

Key actions

Old buildings

As of 2018, old buildings that were built more than 30 years ago accounted for 41% of the total buildings in Seoul. 39.5% of residential buildings, and 47.5% of commercial buildings are classified as old buildings. The ratio of GFA of old buildings in the city was 23.2%, much higher than the average ratio of 14.9% at the national level. In addition, 52% of old housing is apartments (52%) (J. Yoo & C. Yoon, 2020). Therefore, SMG initiated a green retrofitting project to improve the energy efficiency of old buildings to reduce their GHG emissions substantially.

The green remodeling approach for old buildings is rooted in the legislative foundation under Article 12-2 of the *Ordinance on Energy,* effective from 31 December 2019 (ZED Architects & RE Design Workshop, 2021). The approach of greening old buildings encourages the government to support building owners through financial support for building energy efficiency improvement projects, management of a certification system for the green building based on energy efficiency, support to an evaluation program of building energy diagnosis, and surveys for the current energy consumption to set standards for the annual energy use of buildings. Accordingly, the local government will lead the administrative and financial frameworks for greening old buildings in the city (Korea Law Information Center, n.d.f).

The *2050 GHG Emissions Reduction Strategic Plan* recently published by SMG translates the official guidance into practical initiatives and projects. First, SMG will initiate a green remodeling project for 1,532 old public buildings, which accounts for 30% of the total public buildings in the city. The targeted facilities include

I Table 19. Planned green remodeling of old public buildings (Source: Climate and Environment Headquarters, 2021a)

Category		Sub Total	2020-2022	2023-2050
City-owned buildings		401	4	397
District-owned building for vulnerable groups	Senior citizen center	673	37	636
	Daycare center	433	207	226
	Health Center	25	8	17
Total		1,523	256	1267

401 buildings owned by the city, a GFA of 1,000 m^2 or larger, and 1,131 buildings (e.g., senior citizens centers, daycare centers, and community health centers) owned by district governments and built 20 years ago or more. The project focuses on transforming buildings with efficient energy use and a user-friendly environment, especially for those vulnerable groups in society, as they are particularly exposed to the extreme summer heat and winter cold. Old buildings under the *Zero Energy Building (ZEB) scheme initiated by SMG* are expected to meet energy efficiency Grade 1^{++} or beyond, and energy self-sufficiency increased to 20% or more. Also, those under the national green remodeling initiative are expected to increase energy efficiency by 30% or more. With a target to green 1,532 old buildings by 2050, SMG will set up Master Planners (MP) to manage the project by providing consultation service and producing summary reports (Climate and Environment Headquarters, 2021a, 2021c, 2021d).

For example, SMG initiated green remodeling projects with the same level of energy efficiency as ZEB for senior citizen centers in 2020. As a result, three senior citizen centers have been transformed into green buildings meeting energy efficiency Grade 1^{++} or beyond. The senior community center in Nowon-district uses passive technologies (e.g., thermal insulation and airtightness) and active technologies (e.g., solar panels, heat recovery ventilator, LED lights). With a 100% level of energy independence, the center cuts GHG emissions by 99.3%. The senior community center in Yeongdeungpo-district also combines passive technologies and active technologies (e.g., heat recovery ventilator and highly energy-efficient air conditioners). As a result, the center increases energy independence level to 63%. Another senior community center surrounded by buildings in Yeongdeungpo-district uses only passive technologies. Seoul plans to transform 12 senior community centers into green buildings by the end of 2021 (Climate and Environment Headquarters, 2021g).

SMG implemented a green remodeling project for daycare centers in cooperation with the Ministry of Land, Infrastructure, and Transport (MoLIT). The MoLIT launched a signature project for the green remodeling of public buildings to increase the effectiveness and promotional effect of the green remodeling initiative with the active engagement of local governments (Kharn, 2021). According to the online newsletter of Dobong-district, the district shortlisted 14 public daycare centers for the green remodeling project. Since 2021, the project has been implemented with design and financial support from Korea Land and Housing Corporation (LH) and a total of 4.7 billion KRW (approximately 3.9 million USD) funding, including 2.4 billion KRW (approximately 2 million USD) from the national government, 1.6 billion KRW (around 1.3 million USD) from SMG, and 0.7 billion KRW (approximately 0.6 million USD) from the Dobong-district office (Dobong District Office, 2021). In particular, SMG selects Dosun daycare center as one of the best cases of green remodeling. SMG transformed the old building built 31 years ago with low energy efficiency and poor indoor environment into a green building using both passive technologies and energy-efficient equipment, such as energy-efficient heating and cooling systems and eco-friendly boilers. Together with the green remodeling project for daycare centers, SMG will further expand cooperation with the national government to assess the effectiveness of retrofitting public buildings (Climate and Environment Headquarters, 2021g).

In addition, SMG encourages private buildings to join the Building Retrofit Project (BRP). According to the reports published by SMG, SMG provides financial support to greening private, old buildings to lower the financial barrier, a huge obstacle to private engagement. First, SMG supports a loan for the cost of green remodeling with a source from the city's Climate Change Fund. In 2021, 6 billion KRW (around 5 million USD) will be invested in greening the private, old buildings with zero interest, which has been adopted since March 2021. Second, for neighborhood-convenience facilities and detached housings built at least ten years ago and with a GFA of 3,000 m^2 or smaller, SMG supports a

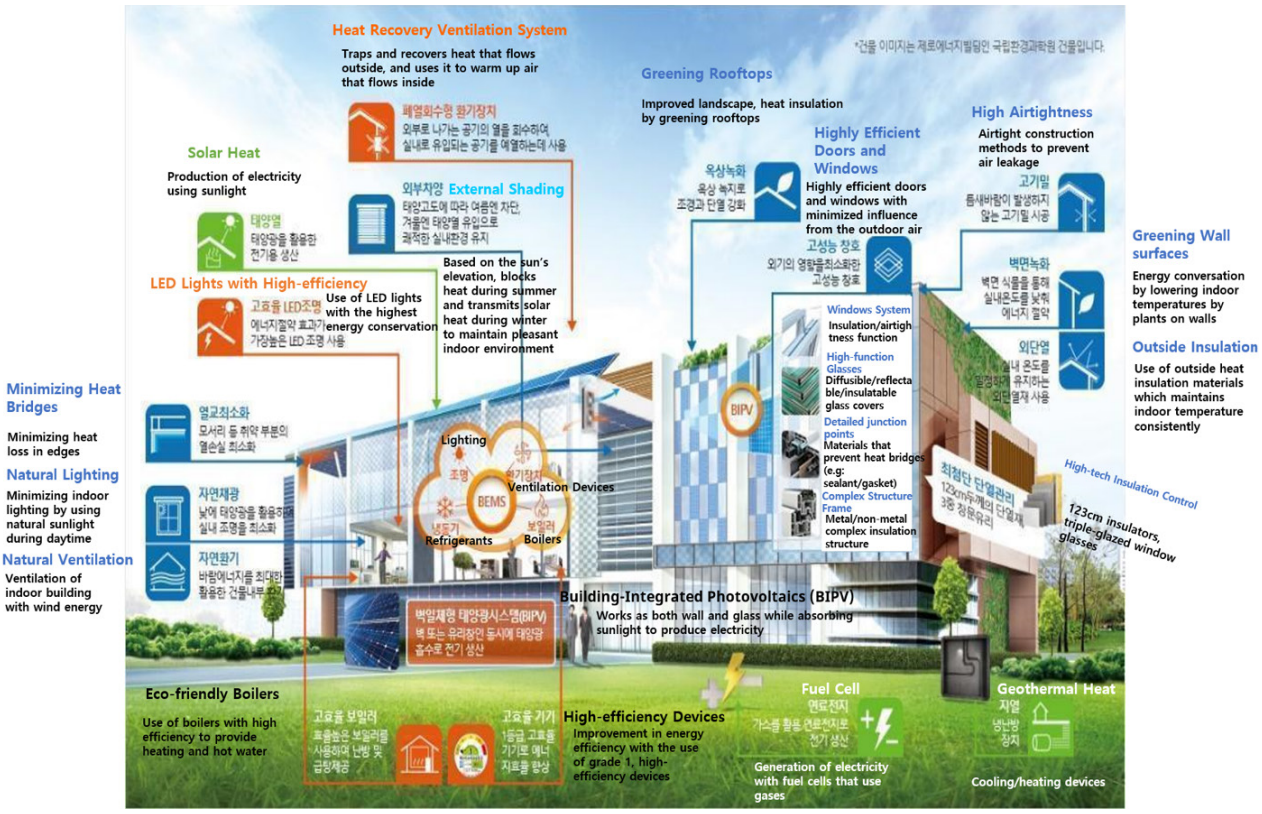
commission fee on energy efficiency grade certification and construction cost for green remodeling depending on energy efficiency grade. Third, SMG operates a financial support program connected with the Home Improvement Program designed to finance half of the construction costs for greening old low-rise houses within the Home Improvement Support Zone. The government provided up to 15 million KRW subsidies to detached and multi-family houses and up to 20 million KRW to multi-family and multi-unit dwellings. SMG plans to promote the program in terms of scope and effectiveness. As 30 zones will be included under the program in 2021, housings in a total of 165 zones will benefit from energy efficiency and consequent additional subsidies on 10% of construction cost by using materials and equipment with a high level of energy efficiency (Climate and Environment Headquarters, 2021a, 2021c, 2021d).

SMG recently published the Second Comprehensive Plan for Climate Action (2022-2026) and updated strategies for reducing greenhouse gas emissions from the building sector. SMG chooses the promotion of the Building Retrofit Project (BRP) for one million buildings, one-fourth of buildings in the city, as one of five major strategies for the building sector. SMG develops three strategies for private buildings. Frist, SMG installs eco-friendly boilers and LED lights at 120,000 public housings. Second, SMG installs eco-friendly boilers and LED lights at 80,000 housings of a lower-income group and provides installation costs. Third, SMG supports a loan for the BRP for 800,000 detached housings with zero interest and installs eco-friendly boilers at the detached housings (SMG, 2022).

New buildings

Between 2014 and 2018, the number of buildings decreased by 4.6%while the areas occupied by buildings increased by 5.6%. This implies that new buildings have increased with the GFA increase (J. Yoo & C. Yoon, 2020). Therefore, measures for newly built buildings become as crucial as green remodeling for old buildings to cut GHG emissions from the building sector to a substantial degree. Thus, SMG developed specific strategies to promote Zero Energy Building (ZEB) to improve the energy efficiency of newly built buildings. The SMG's approach to ZEB aligns with the national approach and accordingly expects to facilitate the expansion of ZEB nationwide.

According to the official website for ZEB in Korea, ZEB refers to building with minimized energy demand for external sources by using passive and active technologies. In terms of passive technology, buildings reduce energy demand for heating and cooling by enhancing thermal insulation and airtightness. Active



I Figure 30. Technologies applied to Zero Energy Building (Source: Zero Energy Building Certificate System, n.d.c)

technology minimizes buildings' energy demand for external sources through energy-efficient equipment and Building Energy Management Systems (BEMS) while maximizing renewable energy generation from power generators installed inside and outside buildings (Zero Energy Building Certificate System, n.d.a).

Similar to the green remodeling initiative for old buildings, the public sector takes the lead in promoting the nationwide ZEB initiative for newly-built buildings (Zero Energy Building Certificate System, n.d.c). Currently available ZEB certification consists of five grades (Zero Energy Building Certificate System, n.d.b):

- Grade One: over 100% level of energy independence;
- Grade Two: from over 80 to under 100% level of energy independence;
- Grade Three: from over 60 to under 80% level of energy independence;
- Grade Four: from over 40 to under60% level of energy independence; and
- Grade Five: from over 20 to under 40% level of energy independence.

Given that the national government adopts a mandatory regulation for ZEB, SMG adopts the compulsory regulation of ZEB for the newly-built public buildings with a GFA at 1,000 m^2 or larger from January 2020 and for facilities with a GFA at 500 m^2 or larger from January 2021 (Climate and Environment Headquarters, 2021d).

Aside from initiatives for individual buildings, Seoul also addresses energy self-efficiency innovation of housing complexes. For example, Seoul city joined an R&D demonstration project for ZEB between 2013 and 2017 under the MoLIT leadership, known as the Nowon Energy Zero Housing Complex Project (Ministry of Land, Infrastructure, and Transport, 2019). This R&D demonstration project engages multi-stakeholders, including national and local governments, academia, and a construction company, in developing a successful ZEB model applied across Seoul and other cities. The housing complex combined passive technology, such as thermal insulation and air-tightness technology, for building envelopes to minimize energy loss and energy demand. As a result, passive technology successfully reduced 61% of the energy demand, while active technology reduced another 13%. The remaining 26% of energy demand is met by renewable energy generation (solar panels and geothermal heat pumps) within the housing complex, generating a surplus of 7% that is transmitted to the electric grid. As a result, each household only pays an average of USD 27 each month for electricity use. In addition, the housing complex innovation contributed to raising public awareness on the importance and effectiveness of ZEB in stabilizing the indoor temperature of individual housings, consequently saving energy and cost and improving indoor air quality (Ministry of Land, Infrastructure, and Transport, 2017; K. Cho, 2018; Lim and others, 2021).

SMG also developed the *Roadmap for ZEB Mandatory Regulations on Newly Built Private Buildings* to engage the private sector. The mandatory regulations for newly-built private buildings at the city level will be one or two years earlier than the national level. Non-residential buildings with a GFA at 100,000 m^2 or larger and residential buildings with 1,000 households or more will come under mandatory regulations from 2023; non-residential buildings with a GFA at 10,000 m^2 or larger and residential buildings with 300 households or more will come under the rules from 2024 (Housing and Architecture Headquarters, 2021).

Moreover, SMG tightened construction standards for green buildings. With a partial amendment to the construction standards coming into effect in 2021, the newly built residential and non-residential buildings have to meet energy efficiency Grade 1^{++}. In addition, the level of energy independence with renewable energy generation also has to increase to 12% for residential buildings and 16% for non-residential buildings. With the further amendment to the construction standards in 2023, the requirement for both residential and non-residential buildings to meet energy efficiency Grade 1^{++} will be the same; the level of energy independence with renewable energy generation has to increase to 20% for both building types (Housing and Architecture Headquarters, 2021).

In addition to the mandatory regulations, Seoul also adopted incentive measures to encourage voluntary engagement of the private sector in green building schemes. When meeting ZEB criteria, seven types of stimuli - either national or local level or both - are available to newly-built private buildings. Table 20 shows different types of incentives provided for buildings meeting ZEB criteria. In addition, SMG plans to develop an incentive system tailored to the city and extend its application (Housing and Architecture Headquarters, 2021).

GHG emissions cap

SMG adopts a GHG emissions cap to control emissions

I Table 20. Incentives for the engagement of the private sector in Zero Energy Buildings (Data source: Housing and Architecture Headquarters, 2021)

Incentive categories	Description
Subsidies for renewable energy generators installation	When non-residential buildings with the preliminary certification for ZEB apply for the installation, they will receive extra points
Subsidies for energy use rationalization	When non-residential buildings with the preliminary certification for ZEB invest in energy efficiency equipment, long-term and low-interest rates will be applied to a part of the expenditure
Contributed acceptance for public infrastructure establishment	Buildings with the certification for ZEB take up to 15% less responsibility for the contributed acceptance*
Reduced certification fee	Buildings that are not subject to ZEB mandatory regulation will pay the certification fee reduced by 30% to 100%
Increased credit line for the National Housing and Urban Fund loan	Residential buildings (public rental housing, general sales apartments, national rental housing, happiness housing (public housing), private rental housing) with the certification for ZEB will have the increased credit line for the National Housing and Urban Fund loan by 20%
Lowered construction standards	Buildings with the certification for ZEB will be subject to the construction regulations on floor area ratio and height relaxed by 11% to 15%
Reduced property acquisition tax	Buildings with the certification for ZEB will pay the property acquisition tax reduced by 15% to 20% by December 31

from buildings. This scheme allows a certain amount of GHG to be emitted from buildings according to the unit area and provides either incentives or disincentives to buildings according to their performance results t. Furthermore, SMG initiated a demonstration project for the GHG emissions cap for 51 public-owned buildings with GFA of 1,000m^2 or larger owned between 2021 and 2025. The demonstration project targets to cut GHG emissions from buildings by 5,000 tons by 2025 compared to the GHG emissions level over the last three years. Besides, SMG works with the city's think-tank, Seoul Institute, to research and develop action plans for the scheme (Climate and Environment Headquarters, 2021d).

The demonstration project and research outcome help SMG draw a roadmap for the GHG emission cap. The emission cap scheme for the public sector will take effect from 2021 with a demonstration project for 51 public buildings and will expand in the following phases. The emission cap scheme for the private sector also commences with a regulatory reform from 2021. After that, it will develop in the next stage (Climate and Environment Headquarters, 2021d).

Besides, SMG has introduced the Seoul GHG emissions management system using Geographic Information System (GIS) technology. This system enables SMG to monitor energy use such as electricity, urban gas, and heat, and GHG emissions converted from energy use at once. Moreover, the system as baseline data for internal reference will help assess the effectiveness of the city project in reducing GHG emissions from the building sector (SMG, 2021f).

Energy performance certification

I Table 21. Roadmap for building GHG emission cap in Seoul (Source: Climate and Environment Headquarters, 2021a)

	From 2021	From 2022	From 2023
Public Building	[Phase 1] Pilot project for Municipal buildings with an area of over 1.000m^2	[Phase 2] Municipal buildings with an area of over 1.000m^2	[Phase 3] Gradual expansion to include city-funded agencies, district offices
Private Building	[Preparation] Lay a legal ground by revising Green Building Establishment Support Act	[Phase 1] Pilot project for high energy consumption buildings	[Phase 2] Start with buildings with an area of over 10,000m for gradual expansion

* Contributed acceptance is defined as *"the gratuitous transfer of ownership of property to the State by a person, other than the State, and acceptance thereof by the State"* under the State Property Act

According to SMG, a mandate for energy performance certification began in 2020 and will be expanded in the future. Starting from municipally-owned buildings in 2020, the demonstration project for the mandate for energy performance certification applies for 60 buildings in 2021 (Climate and Environment Headquarters, 2021d). The *2050 Seoul Climate Action Plan* presents project expansion in the coming years. The demonstration project will further apply to 401 municipal buildings with a GFA of 1,000 m^2 or larger by 2024; municipal buildings and buildings with a high level of energy consumption by 2025; private buildings with a GFA of 1,000 m^2 or larger from 2026; private buildings with a GFA of 500 m^2 or larger from 2030. All buildings in the city will come under the energy performance certification scheme by 2050. Buildings with poor performance will come under an additional restriction on property transactions or receive improvement orders. Furthermore, for buildings with a GFA of 500 m^2 or larger, energy performance reports will eventually become compulsory to property transactions with an amendment of the *Licensed Real Estate Agents Act* (Climate and Environment Headquarters, 2021a).

The actions mentioned above consist of a solid basis for the transition of the building sector. According to the 2050 Seoul Climate Action Plan, Seoul plans to create 8,571 new jobs by 2022 and invest 875.7 billion KRW (787 million USD) by 2025 to accelerate the low-carbon building transition. As a result, Seoul aims to reduce GHG emissions of the building sector by 81% by 2050 from the 2005 level, contributing to the net-zero target (Climate and Environment Headquarters, 2021a).

Barriers and challenges

The biggest challenge to promoting green buildings in Seoul city is the low private sector participation. As mentioned, commercial and residential buildings accounted for 96.2% of the total number of buildings and 83.8% of the entire building area in the city (J. Yoo & C. Yoon, 2020). Public rental housing accounts for only 8% of the total number of housing units in the city, which is lower than the average rate of OECD countries (S. Kim, 2020). Although greening the building sector is still in the initial stage, substantial cuts in GHG emissions from buildings cannot be achieved without the full engagement of the private sector.

The lack of private sector participation is mainly due to a lack of financial incentives as the profit-driven companies are reluctant to invest heavily in constructing ZEBs. According to the report published by the Korea Energy Agency, the Nowon Energy Zero Housing Complex project cost 49.02 billion (around 41.15 million USD) KRW, including 46.92 billion KRW (approximately 39.39 million USD) for construction and 0.21 billion KRW (around 0.18 million USD) for R&D. Compared to standard public rental housing, the construction cost for the Nowon Energy Zero Housing Complex in terms of energy increased by 24.5%, including 14% increase from passive technology and 10.5% increase from active technology (Y. Cho et al., 2017). Incentives provided by the national and local governments are not commensurate with initial investments. Even available incentives benefit large-sized buildings rather than small-sized buildings with a GFA of smaller than 1,000m^2, which account for 95% of the total number of buildings in the city (M. Kim & Nam, 2019). Thus, practical incentives that benefit small private buildings and alleviate their financial burden need to be developed.

Another challenge in private sector engagement is the lack of knowledge of green building technology. The theme of carbon neutrality has emerged recently with a growing need for bold actions to tackle climate change. However, the ZEB concept of today is still new and evolving in application. Moving beyond the traditional idea of energy efficiency, the ZEB adopts the energy prosumer concept to maximize energy independence through the combined use of passive and active technology. According to a senior researcher from the Seoul Institute of Technology, the challenge arises from accessibility to ZEB knowledge and technology to general architects and builders in the building construction sector. Moreover, the knowledge gap between the technical concept of ZEB and architectural construction drawings at construction sites is much more challenging. Therefore, the technical capacity of architects and construction workers needs to be strengthened to design green buildings (Ryu, 2021).

Lessons learned

Seoul city's green building initiatives align with the national and local efforts to achieve carbon neutrality by 2050. The alignment with the policy-based framework provided by the national and local governments is an engine for sustainable and practical green building initiatives. By synergizing national and local government efforts, the joint R&D initiatives led by MoLIT and SMG generated positive outcomes and opportunities for replication. It also enabled SMG to develop local implementation plans for green building one or two years earlier than the timeframe suggested by the national roadmap.

Another success factor for SMG's green building initiatives is the holistic approach. Firstly, SMG has developed strategies tailored to both old and newly-built buildings, such as green remodeling and ZEB. The property market of Seoul city is expanding substantially, even to the suburbs. Due to the current market demand, ZEB strategies, mainly designed for newly-built buildings, have been developed to mitigate GHG emissions. However, in the longer term, the demand for new buildings will significantly decline to nearly zero when all the urban areas are fully occupied, potentially contributing to a market for green remodeling designed for old buildings.

SMG also took another holistic approach that integrates energy efficiency measures, universal and people-oriented design, and decentralized renewable energy generation. Instead of silo energy-saving solutions, the city aims to design better housing complexes, buildings, facilities to create a livable environment indoors and outdoors. As shown in the Nowon Energy Zero Housing Complex, advanced technologies are applied to improve the energy efficiency of buildings and even to expand the role of housing into an energy supplier beyond energy consumption through renewable energy generation. Although the initial investment cost is higher than general housing complexes, it effectively reduced GHG emissions and electricity use and enhanced indoor air quality. Moreover, policy measures and incentives to mainstream such technology may enable scalability and replication in more housing complexes and potentially reduce costs and attract more private sectors' involvement by achieving economies of scale.

4.2.2.2 Beijing

Background

In China, civil buildings refer to buildings for people to live in and conduct public activities. Civil buildings comprise residential and public buildings (government-owned and commercial facilities) where public activities occur. The total area of urban civil construction in Beijing reached 805.7 million m^2 in 2015, of which energy-efficient buildings (*Jie Neng Jian Zhu*) reached 599.37 million m^2 and accounted for 74.4% of the total area. The share of energy-efficient buildings increased by 17.3% from the 2010 level. Most of the buildings in Beijing are residential buildings (60.7%) with a total floor area of 489.46 million m^2. In comparison, public and commercial buildings account for 39.3% and 316.23 million m^2. The rate of energy-efficient buildings amongst the entire civil buildings, residential buildings, and public buildings was 74.4%, 92.2%, and 46.8%, respectively (BMCHURD, 2016). As public buildings have the lowest rate of energy-efficient buildings, upgrading public buildings has been a priority in Beijing's building energy-efficiency policies. In Beijing's rural areas, the civil building areas are 210 million m^2, in which 180 million m^2 and 30 million m^2 are residential and public buildings, respectively (BMCHURD, 2016a).

The building sector is a vital contributor to Beijing's energy consumption. In 2014, the total energy consumption of the civil buildings reached 31.14 million tce, accounting for 45.6% of the city's total energy consumption. The energy consumption per square meter of urban civil buildings was 30.91 kg of coal*. As urban areas have a higher density of civil structures, the energy consumption of buildings is much higher in cities (88%) than in rural areas (12%), i.e., 27.38 million tce for urban buildings and 3.76 million tce for rural buildings (BMCHURD, 2016a).

Electricity and heat demands are the building sector's two major energy consumption activities. In 2014, energy consumption for heating was 10.68 million tce, and the consumption per square meter of buildings was 13.9 kg of coal. In urban areas, the power consumption of the residential building was 14.57 billion kWh, and the consumption per square meter of buildings was 31 kWh; the total power consumption and the power consumption per square meter of public buildings were 30.89 billion kWh and 103.8 kWh, respectively (BMCHURD, 2016a). The power consumption of public buildings was much higher than that of private establishments. Therefore, decarbonizing the public buildings is essential for developing a low-carbon building sector in Beijing.

Policy framework

The Chinese National Government and the Beijing Municipality Government released policies targeting the overall buildi ng sector and key actions (Table 22). In 2016, Beijing published *the 13th Five-Year Plan for Energy-saving Development of Civil Buildings*, which served as a basic plan to guide the building sector development from 2016 to 2020. Beijing also released specific action plans to work on critical priority areas, including old building renovation, green building promotion, energy consumption monitoring, and

* The data only includes the energy consumption for heating and power.

I Table 22. Key building policies

	National policies	Beijing
Main strategies	the 13th Five-Year Plan for Building Energy Saving and Green Building Development	the 13th Five-Year Plan for Energy-saving Development of Civil Buildings (2016-2020)
Old building renovation		Beijing Action Plan for Promoting Energy Efficiency of Public Buildings (2016-2018)
New energy-efficient building promotion*	Green Building Development Action Plan (2020)	Beijing Green Building Development Action Plan (2020-2022) Key Points of Prefabricated Buildings Work in Beijing in 2020
Energy efficiency monitoring	Notice on Strengthening the Energy Efficiency of Public Buildings and Improving the Construction of Key Cities	Beijing Action Plan for Public Building Energy Efficiency Improvement (2016-2018) Beijing Residential Building Energy Conservation Management Measures (2014)
Standard and grade setting	Assessment standard for green retrofitting of existing buildings (GB/T51141-2015), 2015 Assessment standard for green building, 2019 Standards for building carbon emissions measurement (GBT-2050378-2019)	Design Standard for Energy Conservation of Public Buildings (DB 11/687-2015)

standard-setting.

Key actions

Old building renovation

Public buildings renovation

Beijing prioritizes the renovation of public buildings as they consume much more energy than residential buildings. The electricity consumption of public buildings accounts for around 13% of the final energy consumption in Beijing (BMCHURD, 2016b). According to Beijing's 14th Five-Year Plan, the city aims to complete energy efficiency renovation for 30 million m^2 of public buildings by 2025 (Beijing Municipal Government, 2021c). The success of Beijing's public building renovation program will increase energy efficiency and contribute to the low carbon transition of the city's building sector.

The public building retrofitting covers various systems. The systems targeted by the retrofitting initiative included the public buildings' heating, ventilation, and air-conditioning system; the power supply and distribution system; lighting system; monitoring and control system, and others. The government also encouraged small and medium buildings to upgrade building envelopes.

The government has set the minimum energy efficiency targets for building renovation projects. Once the renovation is completed, the energy-saving rate of small to medium buildings must be higher than 15%. In comparison, the energy-saving rate for large structures must be higher than 20%. In addition, the government encourages public buildings to apply for green building certification after renovation. Green building certificates are issued to old buildings upon renovation and eligible new green buildings, both of which are two central pillars of Beijing's sustainable building strategy.

Providing subsidies to property owners is a crucial policy instrument to incentivize energy-conserving renovation of public buildings. The Beijing Municipal Government integrates local policies with the national guidelines on the green renovation of public buildings. For renovation projects included in the national green renovation program, Beijing provided subsidies of 30 CNY/m^2 in addition to the national government subsidy of 20 CNY/m^2.

Residential building renovation

Beijing has been upgrading the energy infrastructure for residential buildings, especially heat supply pipelines and power distribution networks in old residential communities. During the 12th five-year period (2011-2015), Beijing renovated 55.32 million m^2 of existing

* Both old buildings and new buildings can become green buildings. The green building promotion section focuses on new buildings for two reasons. First, the old building renovation section introduces policies targeting existing buildings. Second, most certified green buildings are pilot projects that were newly developed.

residential buildings for energy efficiency improvement, which benefited more than two million residents. Heat supply pipelines and power distribution networks are two main priorities in the renovation program. Beijing upgraded 1,800 km of outdated heat supply pipelines, which connected over 960 senior communities. Meanwhile, it also significantly improved the electricity capacity and reliability in 186 old communities, supporting the electrification progress (Beijing Municipal Government, 2017).

In addition to replacing outdated heat supply pipelines and power distribution networks, Beijing also remodeled facilities inside the residences, especially the old apartments. Furthermore, under the "coal-to-clean energy" transition initiative, 108,000 households in the core areas (Xicheng District and Dongcheng District) started to use electric heating systems instead of conventional heating facilities. In addition,76,000 homes in rural areas began to use clean energy heating systems (Beijing Municipal Government, 2017). Further, to better measure energy consumption, Beijing upgraded the consumption end facilities, such as power meters, gas meters, and heat meters, even as the city strives to achieve multiple meter integration in 100,000 households by the end of 2021 (Beijing Daily, 2021).

New energy-efficient building promotion

Beijing has regularly updated the new building standards to increase building energy efficiency. According to *the Beijing Green Building Development Action Plan (2020-2022)*, the city aims for all new buildings in Beijing to meet the one-start green building requirement in the Green Building Standards, while government-funded building projects must reach two-stars or above. In some key development areas, the new building standards are higher than others. For example, in the Beijing Municipal Administrative Center in Shunyi District, new government-funded buildings and large public buildings must be certified as three-star green buildings.

Meanwhile, Beijing also set targets for different types of energy-efficient buildings. For example, Beijing aims to increase the share of prefabricated buildings to 35% by 2022. Beijing also promotes ultra-low energy consumption buildings. By 2025, Beijing aims to achieve 5 million m^2 of ultra-low energy consumption buildings, and the energy consumption per unit of floor space for heating will drop by 10%.

Green building development

Green buildings in Beijing are defined as buildings that meet the Design Standards of Green Building with the central ideology of harmonious co-existence of man and nature to save resources, protect the environment and reduce pollution during the life cycle of the buildings. To guide green building development, Beijing has taken various actions and published multiple standards and guidance that cover the whole building lifetime from building design construction to building assessment and operation, as shown in Table 23. These actions and measures sent clear signals and incentives to critical stakeholders in green building development.

Prefabricated buildings promotion

I Table 23. Actions and standards to promote green building development in Beijing (Source: the Author)

Stages	Actions	Standards
Building Design	Incorporate green building-related indicators into project planning and contracts Review green building construction maps	Design Standard of Green Building (DB 11/938-2012) (under revision)
Building Construction	Remote video monitoring buildings of over 5,000 m^2 and in central urban districts Publishing dust management evaluation standards and connecting dust management performance with tender eligibility	Management Standard of Green Construction (DB11/513-2018)
Building Completion Acceptance	Organizing green building project acceptance review	Completion Acceptance Standard of Green Construction Project (DB11/T1315-2015) (under revision)
Building Assessment		Assessment Standards of Green Buildings
Building operation	Provide subsidies for two-stars or three-stars green buildings	Interim Measures for the Administration of Municipal Award Funds for Prefabricated Buildings, Green Buildings, and Green Ecological Demonstration Zone Projects in Beijing (2020)

Prefabricated buildings are an emerging trend in China's building industry due to low energy consumption, construction efficiency improvement, and lower carbon footprint during the materialization phase. Although this report focuses on GHG emissions from the building's operational stage, prefabricated buildings are an essential part of Beijing's building policies as the different building types have varying construction impacts on the climate and environmental impact. Therefore, Beijing also released standards and guidance for prefabricated buildings.

Beijing promotes new building projects to apply prefabricated building technology. Beijing mandates all types of indemnificatory buildings and government-financed buildings to adopt prefabricated building technology, except buildings with an above-ground construction area of fewer than 20,000 m^2 (BMCHURD, 2020c). Promoting prefabricated buildings amongst these public buildings increases its market competitiveness.

In addition to government-financed buildings, Beijing set similar requirements for commercial and industrial buildings. The relevant conditions are embedded into the building project bidding, auction, and listing documents of development projects in state-owned land. The requirements for prefabricated buildings differ across the urban districts in Beijing, with more stringent requirements applied within the urban core as a move to significantly reduce energy consumption and carbon emissions. For example, new commercial housing development projects at the six core urban districts of Beijing (Dongcheng, Xicheng, Chaoyang, Fengtai, Shijingshan, and Haidian) must fulfill the requirement. At the same time, the standards only apply for construction projects above 50,000 m^2 in the Tongzhou district. Aside from commercial buildings, the condition also extends to newly constructed industrial plants and warehouses (BMCHURD, 2020c).

Subsidies to green buildings and prefabricated buildings

Subsidies are a vital policy tool to support green building and prefabricated building development in Beijing. In 2020, Beijing released new subsidy policies, especially green and prefabricated buildings. These projects are eligible to receive different levels of subsidies based on the application of green technologies. As the costs for green building and prefabricated building technologies are higher than conventional technologies, the contributions from the government enhanced the competitiveness of green technologies in the market.

Energy consumption monitoring and quotas

Another critical policy instrument for improving building energy efficiency is imposing total energy and electricity consumption quotas. In 2012, Beijing released *the Public Building Energy Consumption Quota and Differentiated Price Work Plan* (2012) and *the Interim Measures of Beijing Municipality for the Administration of Electricity Consumption Quotas for Public Buildings* (2012). The energy consumption quota applies to buildings with over 3,000 m^2, in which more than 50% are categorized as public building areas. In 2020, Beijing updated the quota for building energy consumption and issued *the Interim Measures for Electricity Consumption Quotas Management* (BMCHURD, 2020b).

The key is determining electricity consumption quotas for various buildings. The following equations, Q1 and Q2, show how to calculate electricity consumption quotas. The allocation is the smaller value between Q1 and Q2. According to the measurement approach of Q1,

I Table 24. Subsidies for green buildings and prefabricated buildings in Beijing (adapted from BMCHURD, 2020a)

Building types	Requirement	Subsidy	Notes
Green building projects	Two-stars green buildings	50 CNY/m^2	The maximum reward for a single project is 8 million CNY
	Three-stars green buildings	80 CNY/m^2	
Prefabricated buildings	For projects mandated to apply prefabricated building technology: assembly rate≥70% prefabrication rate ≥50%	180 CNY/m^2	Projects will be rewarded based on the above-ground building area, and it shall not be less than 5,000 m^2 The maximum reward for a single project is 25 million CNY
	For projects that voluntarily apply the prefabricated building technology: assembly rate ≥50%; prefabrication rate (the building height under 60 meters) ≥40% prefabrication rate (the building height above 60 meters) ≥20%	180 CNY/m^2	

the public buildings covered in the mechanism need to consume at least 2% less electricity than the average level.

Q1 is 2% lower than the average value of historical electricity consumption in the previous five years

$$Q_1 = \frac{E_{i-1} + E_{i-2} + E_{i-3} + E_{i-4} + E_{i-5}}{5} \times (1 - 2\%)$$

i : *the year in which the electricity consumption quota is to be released*

$E_{i-1}, E_{i-2}, E_{i-3}, E_{i-4}, E_{i-5}$: *historical electricity consumption (kWh)*

Q2 is the result that multiplies the building area by the average electricity consumption per unit area of the same type of building.

$$Q_2 = \overline{e} \times A$$

A : *construction area*

$\overline{e}$: *The average electricity consumption per unit area of similar buildings in the previous year (kWh/m^2)*

The government reviews the annual electricity consumption of targeted public buildings. For example, suppose a building consumes 20% more than the electricity consumption quota and 20% more than the total energy consumption quota. Then, the building owner will face various penalties, such as ineligibility to apply for green building certification and mandatory submission of annual energy auditing reports. On the other hand, if a building exceeds the energy consumption quota for two consecutive years, the building will be fined and included in the orderly curtailment mechanism (BMCHURD, 2020b).

Building Energy Efficiency Standards

Beijing published multiple standards to guide the low-carbon transition of the building sector. The government mentioned above that the government set green building standards covering the entire building lifetime. Beijing also enforced building energy efficiency standards as a direct effort to push the low carbon transition.

Beijing regularly updates the energy-saving design standards for new building projects. In 2013, Beijing started implementing the Design Standard for Energy Conservation of Residential Buildings (DB 11/891-2012), which reduced the coal consumption quota for residential building heat from 8.82 kg coal to 6.3 kg coal per m^2. In 2015, Beijing started implementing the new *Design Standard for Energy Conservation of Public Buildings (DB 11/687-2015)*. The regular update of the energy consumption standards pushes building developers to reduce the climate impact of new buildings.

Challenges and barriers

Beijing faces several challenges to decarbonize the building sector. Firstly, the energy consumption of the building sector is expected to increase because of the continuous urbanization process and increased standards of living. Considering Beijing's energy system still largely relies on fossil fuels, reducing emissions from buildings will require more stringent measures and push for innovation. Replacing fossil fuels, especially gas, with low-carbon energy will be a critical challenge to decarbonize the building sector. This challenge is particularly essential for old buildings as some are equipped with outdated technologies. Second, green buildings only account for a small share of all buildings, and there are many old buildings in Beijing. Transforming old buildings into green buildings is critical and challenging and requires a high level of public engagement. Third, the discussion and innovation in integrating the building and renewable energy nexus has been limited, with a vast potential to scale and replicate.

Lessons learned

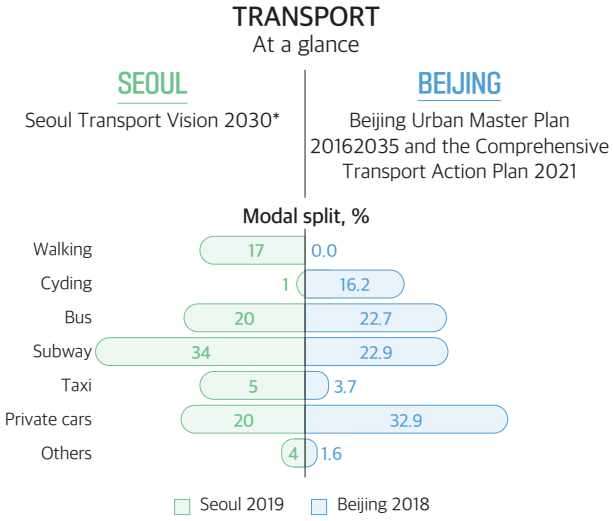
This session shed light on how Beijing promotes the low-carbon transition of the building sector in the construction and operational phases through regulations, subsidies, and policies. Firstly, Beijing has advocated for renovation and retrofitting old buildings to improve energy efficiency, especially worn public buildings. Beijing's renovation program focused on updating the energy system within buildings, such as heat networks and power grids.

Secondly, green buildings and prefabricated buildings encourage new urban construction methods. In this regard, Beijing introduced new regulations, subsidies, and new standards for building programs. As a result, as of 2019, 402 projects in Beijing are certified as green buildings, representing 45.9 million m^2 of building areas, while 93% of the green building areas are certified as two stars or above. In 2019, the prefabricated construction areas were 14.13 million m^2, accounting for 26.9% of the newly added floor area.

Thirdly, Beijing instituted the energy consumption monitoring quota to push large public buildings to reduce their energy consumption. Between 2014 and 2018,

the energy consumption monitoring system decreased 1.97 billion kWh of electricity consumption in public buildings. Beijing also regularly updates the building energy efficiency standards to foster the development of energy-efficient buildings. These efforts have been instrumental in Beijing's effort to improve building energy efficiency and reduce energy use per floor space for existing and new buildings.

4.2.3 Transport



* Seoul Transport Vision's modal share excludes walking and cycling. In this case, the modal share is: 24.5% private cars; 24.0% bus; 41.6% subway; 5.7% taxi; 4.2% others

Key transport figures 2019

Seoul	Beijing
Walking	**Green mobility**
• 2,788 km pavements	• 894 km pavement completed
• 70.3 min/ day on pavements	• 540 million/year cyclists
• 940.6 km cycling routes	
Public bus	**Public bus**
• Public bus 353 routes	• 27,632km
• 7,413 buses	• 1,158 routes
• 4.28 million users/ day	• Bus-only lane: 952km
• Peak-hour speed: 20.6 km/hr	• Peak hour speed: 17.02 km/hr
Subway	**Subway**
• 10 lines, 350.1 km	• 23 lines, 699 km
• 325 stations	• 405 stations, 62 transfer stations

* Seoul Transport Vision's modal share excludes walking and cycling. In this case, the modal share is: 24.5% private cars; 24.0% bus; 41.6% subway; 5.7% taxi; 4.2% others

4.2.3.1 Seoul

Seoul is an economic engine behind Korea's impressive industrialization in the past 40 years. The demographic transition and urbanization transformed the city and lifestyle, leading to a boom in automobile ownership. Between 1980 and 2009, car ownership increased by 1,341% in Seoul and 2,907% in the metropolitan area. By 2014, the number of vehicles on the road dramatically increased by 130 times, while the road lengths expanded only 1.2 times (8,241 km) since 1980 due to the limited road space (SMG, 2019). With 32.1 million vehicles on the road each day, traffic congestion worsened with average car speeds lower than 16 kilometers per hour (km/hr) in the urban core, and the estimated social cost was estimated to be 7 billion KRW (6 billion USD) in 2009 (Center for Liveable Cities, 2015). At the same time, the quality of public bus service deteriorated, particularly the travel speed reduced by 13% between 1996 to 2002 (from 18.35 km/hr to 16 km/hr) (IGLUS, 2019). The increase in automobiles combined with the decreased popularity of public transport posed pressure to the environment, transportation, and urban development.

In 2017, Korea suffered from the highest fine particulate matter amongst the OECD member countries. Seoul metropolitan area also faces seasonal air pollution episodes, even at hazardous levels. 52% of ultrafine particles originate from the transport sector. For instance, most of the NOx emissions originate from diesel cars (67%), followed by gasoline cars (12%); compressed natural gas (CNG) vehicles (10%); and liquified petroleum gas (LPG)-fueled vehicles (9%). Thus, air pollution mitigation is consistently high in the city's priority by curtailing emissions from the transport sector and closing down old coal-fired power plants (SMG, 2015c).

Institutional framework

Policy background

Given the air pollution and transport woes, the city pivoted on the mobility and urban planning strategies through a series of public transport reforms and transformed Seoul's urban form and accessibility while reducing the ecological footprint. The iconic Cheongyecheon stream's flyover removal is a testament to the city's determination to restore public space to the people. Despite the policy interventions, passenger cars still represented 26% of the trips in 2010 and accounted for 56% of the energy consumption in the transportation sector. Therefore, the SMG developed a long-term strategic transportation policy in 2013, known as the Seoul Transport Vision 2030, which envisions "Livable Seoul - without relying on cars". The Vision anchors on three main pillars: (1) Human; (2) Sharing; and (3) Environment. A myriad of transport strategies identified aims to achieve the three transport

objectives by 2030, known as the "2030 triple 30": a 30% reduction in automobile use; a 30% reduction in public transport travel time; and a 30% increment in space used for green transportation. If successful, Seoul could increase the green transport modal share by 10% to 80%, reducing CO_2 emissions from 1.2 tons to 0.8 tons per capita. The Promise of Seoul 2030 also detailed transport goals in synergizing air pollution and GHG reduction goals through sustainable mobility. This paradigm shift emphasizes equitable accessibility over vehicular movement, multimodality over singularity, and soft measures to nudge behavioral change rather than overemphasizing complex infrastructure.

The year 2020 is a year of change worldwide. The Green New Deal, introduced by the national government, will expand 67,000 hydrogen fuel vehicles by 2022 and 2,900,000 vehicles by 2040, while power generation will increase tenfold from 1.6 Gigawatts (GW) in 2022 to 15 GW in 2040 in Korea (Stangarone, 2021). Seoul pledged to achieve carbon neutrality by 2050 under the "2050 GHG Reduction Strategy through the Promotion of the Green New Deal" in July 2020 to accelerate the transition towards a low-carbon and green economy and achieve net-zero emissions. Green mobility is one of the five key sectors identified in the "2050 Seoul Climate Action Plan" (SMG, 2020e), raising the ambition to integrate renewable energy use in transportation.

Institutional structure

In 2017, SMG also budgeted about 2.53 trillion KRW (2,246 million USD) to improve the public transportation system (60.4%), taxi service (13.8%), bus service (14.1%), parking and transport demand management (4.8%), and active mobility infrastructure (2.0%). Thus, enabled by intelligent financial investments and visionary governmental support in sustainable mobility, Seoul managed to kickstart a series of reforms and capitalized on the transport sector to spur innovation, private investment, and economic growth. Table 25 summarizes the different policies and the stakeholders involved in planning and delivering the transportation services.

The following sections will expand how SMG reshaped the urban mobility system to achieve a low-emission and inclusive mobility system based on the three pillars in the Seoul Transport Vision.

Human: a people-oriented city for all

Prioritizing active mobility as a zero-emission mobility mode

Accessibility is a central focus in a people-oriented city and mobility by modifying the infrastructure and urban

I Table 25. Overview of the stakeholders involved in transportation service delivery

SMG: Policy planner, financing, route-planning, and monitoring

	Policies	Operators	Local innovators
Overall	Seoul Transport Vision The Second Comprehensive Plan for Climate Action (2022-2026)		
Walking and cycling	Vision 2030 for a Pedestrian-friendly Seoul 10 Commandments for Paving Blocks		Seoul Street Monitoring Group participated by the residents A.Ma.Zone program
Public bus	Seoul Transport Vision	Bus operating companies	Bus Policy Civic Committee
Subway	Seoul Transport Vision	SMG financed facilities: Seoul Metro National: Korail Private: Metro Line 9 Corporation; Ui Light Rail Transit Corporation	
Ttareungi bike-sharing	Seoul Transport Vision	Seoul Facilities Corporations managed regulated by the Seoul Bicycle Division	
Namun car sharing	Seoul: A Sharing City campaign	SoCar, GreenCar, PeopleCar	
Taxi	Safe Taxi		Various digital companies
Electric mobility	2050 GHG Reduction Strategy through the Promotion of the Green New Deal 2050 Seoul Climate Action Plan		Private corporations


I Figure 31. Former car-oriented Seoul Square (left; KOTI 2015); Post-transformation Seoul Square (right; Time Out)

planning for easy access for all residents, particularly the vulnerable communities. An accessible city is also a walkable and bikeable city, fundamental conditions for highly livable cities. Under the "Walkable City, Seoul" policy and brand, Seoul has been enhancing walkability and narrowing car-oriented roads, and creating more connected sidewalks for pedestrians and cyclists through a series of measures, including removing or converting flyovers to pedestrian walkways and replacing footbridges with crosswalks. The total pavement length in Seoul is 2,788 km, the total area of these sidewalks is 1.2 times that of the Yeouido Island area (SMG, n.d.f).

While Seoul has made great strides in creating an inclusive cycling network, there are still obstacles. The current cycling lanes are predominantly for leisure and do not lead to workplaces; most bike lanes are not separated and protected, although rapidly changing. Seoul aims to increase the bike lanes by 41% from the existing 940.6 km (2019) to 1,330 km and build an extensive bike network that allows residents to bike anywhere in one hour by 2030. This would mean increasing the ratio of bike lanes to vehicle roads from 1.9% to 7%, higher than Amsterdam (4.7%) (Korea JoongAng Daily, 2020). To facilitate integration to public transport, it will also expand boarding to subways with bicycles for more seamless transfer.

Over the years, phased progress has been made to enhance connectivity and walkability to return car-oriented road space to people. For example, the Seoul Plaza transformed from a drab roundabout into a lively urban space popular with the public.

Shared: a transit-oriented transportation system and shared urban space

An integrated and transit-oriented transportation system

Competition amongst the bus operators for the lucrative bus routes and the subway network's opening negatively affected bus ridership, resulting in the sudden surge of single-occupancy vehicles (SOVs). SMG began with ad-hoc public transport strategies that were unsuccessful and exacerbated the issues. Against this background, an ambitious and systemic overhaul of the public transport system transformed the core of the mobility system. In 2019, the daily bus and subway passengers were more than 4 million and 8 million people, respectively, consistently representing more than 65% of the modal split (Seoul Solution, 2021). Seoul aims to make the subway system accessible within a ten-minute walk and increase the public transport modal share up to 75% by 2030.

Seoul metropolitan subway

The heart of Seoul's public transportation system is the Seoul metropolitan subway system based on metro rapid transit, light metro, commuter rail serving the Seoul Metropolitan area, including the Incheon metropolis and satellite cities in the Gyeonggi province. As of 2022, the metropolitan railway network consists of 10 lines, with 350.1 km and 325 stations, and SMG plans to develop the Seoul Light Rail Transit (LRT) to create a 441 km urban railway network. The expansion of the metropolitan subway system achieved the following impacts:

- Travel time decreased by 20%, with an average of 25.4 minutes
- Reduced traffic congestion cost by 15% to 6.8 trillion KRW (5.8 trillion USD)
- 72% of the areas are accessible to a subway station within 10 minutes
- Platform screen doors on subway platforms improved indoor air quality by 35.3% and reduced noise by

7.9%

- 79 Safe Zones at 40 stations with brighter lights and CCTV cameras
- Universally accessible facilities at the subway stations and services (including for the visually or hearing impaired)

Public bus system

With the introduction of the quasi-public bus system, the 353 bus routes and 7,413 buses serve 4.28 million users each day, connecting downtown Seoul with the city's outskirts. There have been studies on Seoul's public bus reform (Seoul Solution, 2017). It is the semi-public bus system that allowed SMG to control route planning according to the demands, while the private companies are responsible for operations in terms of the vehicles, employees, and facilities. Moreover, such a structure facilitated better revenue management regardless of the profitable or unprofitable routes. Finally, the public tender incentivized competitive bidding and improved bus services, leading to increased passenger satisfaction.

Demand-responsive buses also connect residential areas to subway stations, including night buses. The bus-only median lanes (or Bus Rapid Transit, BRT) traverse the middle of Seoul, connecting the east-west corridor. Even during peak hours, buses are faster than private cars as the speed increased by 37% to 20.6 km/hr. All city buses are powered by CNG or electricity. Furthermore, fuel-saving devices are installed on city buses with manual transmissions to allow eco-driving and enhance fuel economy. Considering the aging population's needs and individuals in wheelchairs, Seoul is progressively converting the city buses into low-floor buses, from 27% in 2013 to 65% in 2021, and aims to increase this to 100% by 2025.

Promoting shared mobility as an alternative ownership

The technology-driven innovation from the public and private sector in shared and micro-mobility services is rapidly reshaping the urban mobility ecosystems. SMG initiated the Namun car-sharing systems and Ttareungi public bike-sharing to support last-mile connectivity and encourage sharing in 2013 and 2015.

The Namun car-sharing service began with the intention of reducing car ownership. From 292 outlets and 492 cars when it was first piloted, SMG aims to double Nanum cars to 10,000 by 2022 from the current 4,700 to make car-sharing quasi-public transportation. The car-sharing system is run by SMG but operated by private companies selected through a competitive process. Korea does not have an Uber-like private ride-hailing system to protect the taxi industry, but three major taxi-hailing service platform operators offer convenient taxi-hailing services. Together with Namun car-sharing, they provide an alternative for Seoulites without a car.

The Ttareungi bike-sharing system is designed as a semi-dockless system with docking stations at the high pedestrian traffic areas, such as subway entrances, residential complexes. Users can rent and return bicycles at any station. Since its humble beginning at seven districts with 150 stations and 2,000 bikes (SMG, 2015d), the system expanded across the 25 districts in the city with 1,540 stations and 25,000 bikes in 2020, representing 20 bikes per 10,000 people. When COVID-19 hit, Ttareungi's usage increased by 66.8% compared to the same period in 2019. While public transport passengers decreased by over 20% during the peak commuting hours, the number of Ttareungi users respectively increased by 20.46% and 93.33% during the morning and evening rush hours (SMG, 2020c). The city introduced a QR-code-based rental system to avoid physical touch to protect the users. As cities adapt and recover from the global pandemic, the bike-sharing system fosters the resilience of the urban transportation system.

Environment: minimizing environmental footprint

Transport accounts for 19.4% of the GHG emissions in Seoul (SMG, 2020e), and 52% of $PM_{2.5}$ originate from road transport and construction equipment. The secondary pollutant of $PM_{2.5}$, NOx, accounts for 67% of emissions, mainly from diesel vehicles (SMG, 2015c). Under the One Less Nuclear Power Plant Initiative, SMG proposed reducing 576,000 tons CO_2eq in transport by 2020. While most of the transportation services described thus far have been nudging and encouraging Seoul commuters to opt for a multimodal transportation system rather than SOVs, Seoul also employs Transport Demand Management (TDM) measures to disincentivize personal vehicles to minimize the environmental footprint from road transport.

Financial instruments to disincentivize car-use

The Urban Traffic Readjustment Promotion Act enabled the introduction of the congestion impact fee in 1990 based on the "traffic-generator-pay principle." Seoul implements this through a three-pronged approach. Firstly, the fee is levied around buildings and facilities that induce traffic congestion, such as departmental

stores. The charge is calculated based on the facilities' total floor area and size (approximately 1 USD per m^2). If multiple owners share the building, the congestion fee is shared. As of 2013, the total levied amount reached 105.542 billion KRW (90 million USD), and these fees can be channeled to subsidizing transportation development that benefits the public.

The other aspect of the congestion impact fee system is encouraging private companies to participate in traffic volume reduction programs (such as no driving day, mandatory parking fees, parking thresholds, use of bicycles by the employees), of which the impacts will determine the discount or exemption from paying the congestion impact fee. On top of that, a congestion fee based on the polluter-pays principle is also implemented. Unlike Singapore and London's congestion charging fee applied within the demarcated urban core, Seoul uses a congestion charge on the Namsan 1 and 3 tunnel road on weekdays between 0700 - 2100, leading to a 16.8% drop in traffic volume when it was first introduced (SUSA, 2016). However, there are debates that the existing congestion impact fee and congestion charging are inadequate to attain the ideal impact.

Reducing energy consumption through electric mobility and renewable energy uptake

With the Ministry of Environment, Seoul has been at the forefront of promoting electric vehicle (EV) technology, deployment, and performance through various demonstration projects, including electric two-wheelers, electric and hydrogen buses, hydrogen fuel cell vehicles, and others. Additionally, as the national government identifies hydrogen as the key renewable energy sector to develop, the public-private cooperation models are underway in R&D, financing, and deployment. In 2017, the energy consumption for Seoul's transportation sector was 4,150,000 tonne-of-oil-equivalent (TOE), of which 89% is powered by fossil-based, and the remaining 11% is powered by city gas (7%), electricity (3%), and renewables (1%) (SMG and Seoul Institute, 2020). There has been a slight increase in the use of renewable energy in transport over the years in replacing petroleum, as presented in Figure 32.

Within the Green New Deal context, SMG formed initiatives to accelerate EV deployment by announcing the most ambitious EV plans in 2021 (SMG, 2021c), as follows:

- Deploy 11,779 EVs in 2021 (40% of the accumulated supply from 2009 to 2020)
- Mandate that new public vehicles and their rental vehicles are electric or hydrogen vehicles and 295 EVs are procured for municipal and district institutions
- Increase electric motorcycle (double) and trucks (1.5 times) supply due to COVID-19-induced delivery demands
- Support the procurement of electric trucks for SMEs (more than 10%), but the maximum number per corporation will be ten vehicles to avoid monopoly and opportunists
- Financial assistance for EVs that cost less than 60 million KRW (51,461 USD)
- 40% of the supply for EVs are separately allocated for voluntary replacement by private companies
- Subsidies to replace Grade-5 emission-level vehicles
- Reduce subsidies for electric motorcycles and buses to prevent hoarding and backdoor deals
- Deploy 1,000 hydrogen-powered public buses by 2025 and 11 hydrogen stations (SMG, 2020d)

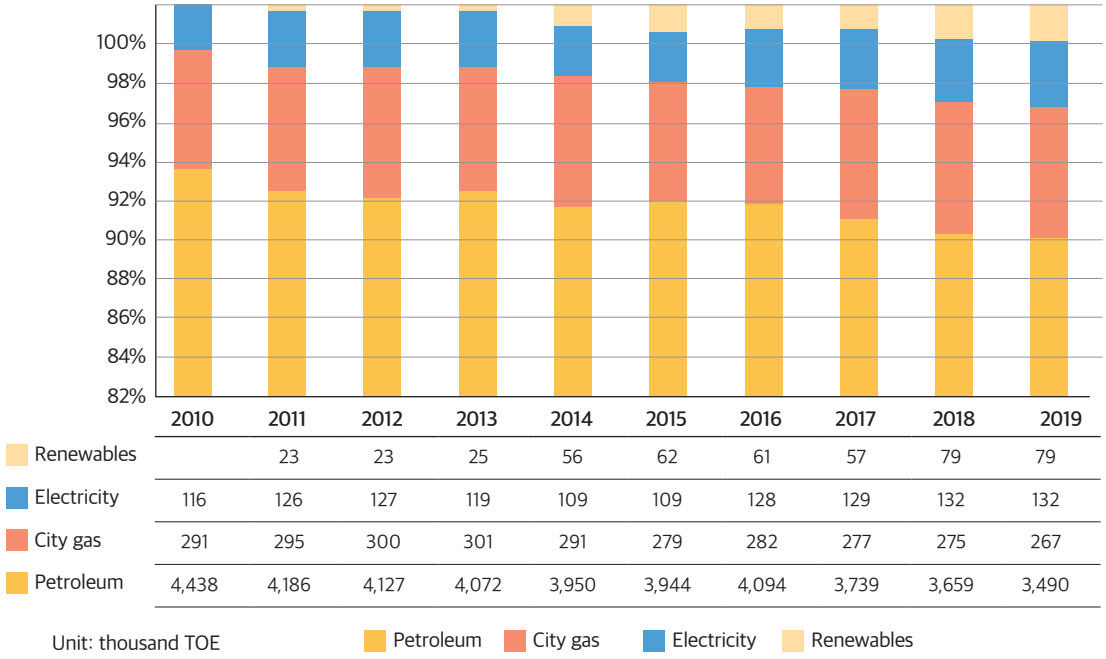
The accumulated registered EVs increased by 56.5% as of 2020 compared to 2019, while diesel and LPG vehicles decreased by 1.2% and 5%, respectively.

Under the newly released The Second Comprehensive Plan for Climate Action (2022-2026), SMG will increase the number of citywide charging stations for EV by tenfold to 220,000 units and establish a "five-minute charging network" within residential areas to increase EV ownership to 10% of the total vehicle population, known as the 10% EV Ratio goal (SMG, 2022a). Through tailored support, SMG collaborates with Korean car companies to introduce an electric mobility ecosystem, while controlling vehicle growth.

Electrification of freight vehicles

Freight demand significantly increased during the COVID-19 period and is also one of the main contributors to GHG and fine dust emissions. Two-wheeled freight delivery vehicles have five times more mileage than passenger two-wheelers. A truck also emits 2.3 times more GHG than a passenger car in Seoul. While SMG has successfully improved passenger transport, the city saw a huge opportunity and need to reduce emissions from the freight sector, a difficult task requiring multi-stakeholder partnership.

Against this background, SMG announced in October 2021 that it will 100% replace internal combustion engine two-wheelers by 2025 and purchase 100% electric delivery trucks from 2022. The business agreement led by SMG was signed in partnership with



	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
Renewables		23	23	25	56	62	61	57	79	79
Electricity	116	126	127	119	109	109	128	129	132	132
City gas	291	295	300	301	291	279	282	277	275	267
Petroleum	4,438	4,186	4,127	4,072	3,950	3,944	4,094	3,739	3,659	3,490

I Figure 32. Share of energy consumption in the transport sector in Seoul (Data source: SMG and Seoul Institute, 2020)

the Ministry of Environment, major domestic delivery companies, electric two-wheeler suppliers, and charging infrastructure companies. To realize the 100% electric two-wheeler delivery vehicles, Seoul is working with Korea Smart E-Mobility Association and Korea Electric Two-Wheeled Vehicle Association to develop and standardize the vehicles and the charging model that can run more than 150 km on a single charge for easy replication and scaling in the long-term. Although there are more than 7,000 electric motorcycles in the city, further adoption has been challenging due to the short mileage (about 50 km per charge) and long charging times (five hours), far below the needed 150 to 200 km per day requirement. The goal is to supply a total of 62,000 electric two-wheelers by 2025, and 56% of them will operate more than five days a week. The initiative is expected to save about 2.45 million KRW each year.

Out of the 6,100 parcel delivery trucks in Seoul, 97% are diesel trucks, and some are even older than 20 years. Therefore, the flagship partnership with the four big logistics companies (CJ Korea Express, Lotte Global Logistics, Hanjin Delivery, and Rosen Delivery) will see 100% new electric trucks being purchased from 2022 onwards to gradually replace polluting diesel trucks with new chargers in the distribution centers. To achieve this, SMG worked closely with the business operators and the Korean Integrated Logistics Association to establish a roadmap for the transition of old diesel delivery trucks by courier companies and set guidelines for delivery companies on electric freight (SMG, 2021d).

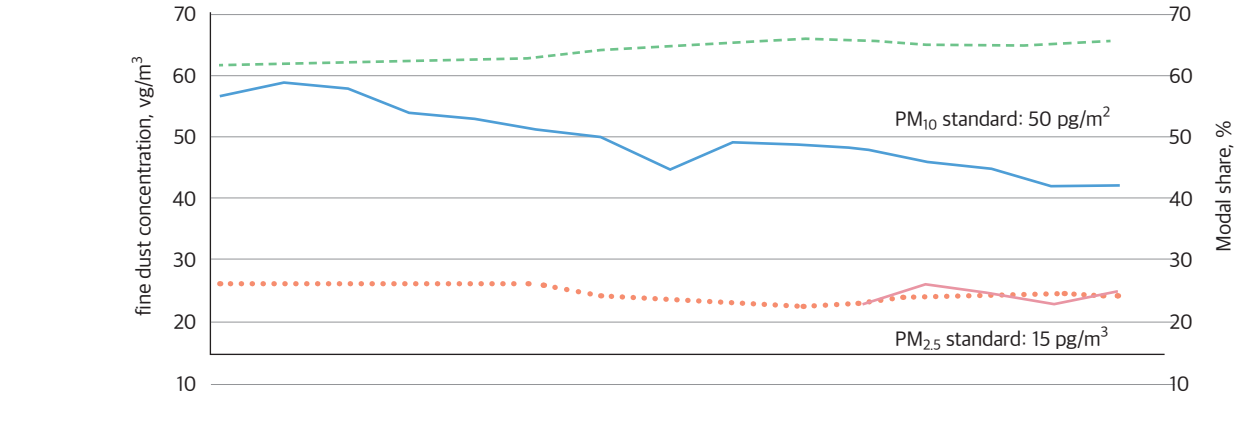
Results and impacts

The approach of SMG to sustainable mobility does not only benefit the residents but creates new opportunities for private corporations to innovate and spur economic growth. In the wake of COVID-19, the years of strategic planning paid off as the city could quickly adapt to the external shock, proving resilience in the transportation system. Figure 33 depicts how the integrated and comprehensive transportation policies and interventions developed slowly increased public transportation ridership at around 65% of the modal split. Additionally, due to the incentives to reduce emissions from diesel-powered vehicles and vehicle-kilometers traveled (VKT) by private transport, the average atmospheric level of fine particles reduced significantly, albeit $PM_{2.5}$ is still a persisting issue.

Barriers and challenges

Although Seoul is the most populated city in Korea, it boasts of the lowest traffic fatality rate, at 1.8 deaths per 100,000 people in 2021, even comparable to New York City (2.6), Sydney (1.9), and London (1.4). Since the introduction of the "Safe Speed 5030", traffic fatality has almost halved from 2004. However, this needs to be upgraded as pedestrians comprise 58.5% of the deaths, 69.4% due to jaywalking. The safety debate is even more relevant as the surge in freight demand poses a risk to delivery drivers due to overworking and speeding.

Even as the national government is ambitious in promoting EVs and hydrogen vehicles, there is still a limit



	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
PM10	57	59	58	54	53	51	50	45	49	49	48	46	45	42	42
PM2.5											23.17	26.25	24.5	23	24.83
Private transport	26.4	26.3	26.3	26.3	26	25.9	24.1	23.5	23.1	22.8	23	24.3	24.4	24.5	24.5
Public transport	62	62.3	62.3	62.5	62.8	63	64.3	65.1	65.6	66	65.8	65	65	65.1	65.6

I Figure 33. The trend in the fine dust concentration and modal share in Seoul (2005 – 2019)
(Data source: Korea Environment Corporation; SMG Clean Air Seoul, 2021)

in the city's carrying capacity in terms of the number of vehicles. Therefore, the challenge lies in maintaining the delicate balance in the electric mobility drive as an economic and climate opportunity without forfeiting the need for sustainable urban mobility.

Lessons learned

Despite being one of the biggest car manufacturing nations and an economic powerhouse, Seoul facilitated sensible automobile ownership while providing inclusive and sustainable mobility through various policy instruments. The tension between industrializing or car manufacturing countries and sustainable mobility often creates conflicting policies and market signals, resulting in inefficient or failed policies that continuously increase automobile ownership, congestion, air pollution, and other urban issues. As demonstrated by Seoul, ***the vital success factor is enabled by a visionary and long-term mobility policy and sustainable financing scheme*** through subsidies and reinvestment of congestion charges to public transportation. The newly launched freight electrification business partnership model is ambitious and innovative in close collaboration with innovators and companies to practically support freight electrification, often a painstaking process in many cities.

Another reason is the ***consistency in policy implementation*** since the reform in the early 2000s and implemented throughout the transport services and modes. This may be driven by SMG's sufficient autonomy and clear direction from the City Transportation Office working closely with the Climate and Environmental Headquarters. In addition, SMG maintains sufficient autonomy over the transport service development, such as the public buses and shared mobility services, to ensure that the innovations support the realization of the city's vision and goals. Working with private companies through competitive bidding processes provides a healthy competitive environment that safeguards the service quality and encourages local businesses to thrive.

Finally, ***most transport interventions that began from a pilot are scaled and replicated*** through clear directives, comprehensive MRV systems to learn from experiences. The engagement of the local communities allowed the different schemes to be more sustainable while increasing awareness. No single policy has more weight than the other, but they harmonize to create an integrated mobility ecosystem that supports carbon-neutral, clean, and people-oriented mobility goals.

4.2.3.2 Beijing

Background

Beijing was once recognized internationally as the "bicycle kingdom" in the 1980s, with bicycle trips representing 63% of the trips in 1986. Fueled by the economic and urban growth in the late 1990s, the bicycle culture diminished while the automotive industry rose rapidly. Private vehicle ownership grew dramatically from less than 1.1 million in 2001 to almost 6 million units in 2018, replacing the USA as the biggest private vehicle market. Beijing in the 1990s was an epicenter

of industrial and economic growth. This means that the automobile modal split rose from merely 5% in 1986 to 34% in 2010 as modernization of the city also made private vehicle ownership a status symbol. As of October 2021, Beijing's vehicle population is 6.82 million (Beijing Traffic Management Bureau, 2021). Triggered by the popularity of automobiles spurred the local industry and economy, the negative externalities triggered by the rise of private cars also exerted pressure on the urban landscape, including traffic congestion, urban sprawl, and significant economic losses.

Beijing became one of the most congested cities globally, with an average travel speed of 15.65 km/hr (Beijing Transport Development Research Center, 2019). According to the AutoNavi navigation application, Beijing commuters spent an average of 1,075 CNY (159 USD) per month due to congestion in 2017. Since the 1990s, Beijing has suffered from hazardous episodes of smog pollution where residents cannot see the buildings across the streets. More than 75% of the air pollution in Beijing originates from vehicular carbon monoxide (CO), particulate matter (PM), and hydrocarbon emissions. Vehicle exhaust emissions account for 45% of air pollution from mobile sources (BMCT, 2021).

China's energy consumption from the transport sector reached 475.35 million tons of CO_2 emissions in 2010 and will reportedly double by 2020 (Liu et al., 2021). The continuous growth in Beijing's transportation sector is closely associated with high energy consumption. Therefore, reducing energy consumption is highly relevant in the carbon neutrality context.

Relevance of regional transport activities

Beijing's role as China's capital city and its international standing elevate the weight of Beijing's transport policies and implementations. According to the "Strengthening the Country through Transport" policy, quick access is a national priority. Most recently, China built the world's fastest magnetic rail between Beijing and Shanghai, traveling at 600 km/hr, halving the travel time to 2.5 hours. Comparatively, the average journey time by train from Paris to Berlin is about 8 hours. The Beijing-Tianjin-Hebei (Jing-Jin-Ji) metropolitan cluster contributes to about 10% of China's total GDP, making freight and regional transport the foundation of the economic powerhouse. However, regional air pollution issues have become so prominent that the State Council promulgated the most stringent Air Pollution Prevention and Control Action Plan 2013 to reduce 25% of $PM_{2.5}$ concentration by 2017 in the region.

Institutional framework

China's Ministry of Transport issued the Four Transport Strategy, the cornerstone for China's future transport development, emphasizing the four pillars: integrated; smart; green; and safe transportation systems. In addition, within the context of the Beijing Urban Master Plan 2016 - 2035, Beijing issues the Comprehensive Transport Action Plan 2021, an annual transport planning document.

Institutional structure

The policies and directives issued at the national level are quickly localized and implemented locally in Chinese cities. For example, when MEE's Air Pollution Prevention Action Plan 2013 highlighted the role of new energy vehicles (NEVs) as one of the ten measures to achieve clean air, Beijing pledged 200,000 NEVs by 2017. The NDRC, under the Ministry of Finance, approves infrastructure expenditures and plays a critical role in cross-coordination amongst the governmental departments and agencies. Beijing Municipal Commission of Transportation (BMCT) is the primary regulator in urban transport policy-making, transport planning, and operations, including the road and subway network, public transportation, active and smart mobility. In addition, BMCT manages and cooperates with other transport agencies in service delivery, maintenance, regulation, and enforcement. The BEE also plays a significant role in environmental protection and electric mobility in coordination with the MBCT.

Beijing's transport policy aims to reduce private vehicle usage based on TDM to maximize carrying capacity, rather than increasing low occupancy personal vehicles' movements. The broad policy goals are to reduce air pollution and GHG emissions while enhancing accessibility and social inclusiveness through congestion reduction and improving the urban functional layout. As a result, through a series of successful and failed initiatives, Beijing successfully controlled the automobile ownership trend.

The following sections will introduce Beijing's approach in addressing the emissions and congestion problems in the sustainable mobility equation. It will be presented based on the Avoid-Shift-Improve framework.

Avoid unnecessary trips through urban planning and design

Transit-Oriented Development

Transit-Oriented Development (TOD) reduces VKT by cars and creates mixed-use, compact, walkable, and accessible neighborhoods that allow residents to live near and use public transport. The Beijing Urban Masterplan 2004 - 2020 first proposed and implemented TOD strategies centered on the metro system since 2003. Faced by accelerating motorization rate and congestion, Beijing realized the importance of integrating spatial development and public transport systems. Economic development and institutional reforms of land and housing markets by urban master planning are the de facto drivers in reshaping home-work spatial relations in Beijing. While the Beijing Masterplan 2004 - 2020 highlighted the need to design a polycentric urban form, it failed to transform Beijing's spatial structure from a monocentric to a polycentric form as population and land-use growth rates outpaced the Masterplan. The red thread in Beijing's Masterplans and transport policies has been strategic investment in the transport infrastructure and TOD to connect the decentralized centers. The Beijing Masterplan 2016 - 2035 emphasizes the integration of the transportation hubs into the spatial planning and creation of dense and mixed urban forms favorable for walking and cycling.

Greening urban freight through Low Emission Zones (LEZ)

The Beijing Clean Air Action Plan 2013-2017 identified urban freight emissions as an instrumental working area. Therefore, the Beijing Green Freight Development Action Plan 2016 - 2020 aimed to develop the green freight industry through four main functional areas: safety management, vehicle quality; operational efficiency; and intelligent transport system (ITS) control. Under the Plan, green freight companies can voluntarily apply for financial incentives based on reduced emissions (NOx and PM). Each ton of pollutant reduced will be rewarded with 60,000 CNY (9,271 USD) (Beijing Municipal, 2016). Beijing also advocates for a modal shift from road freight transport to rail transport of bulk goods for critical commodities, including steel, daily necessities, and construction materials. Between 2017 and 2020, bulk goods arrival via rail increased by 6.4% and reduced about 10,000 tons of CO_2 (Beijing Municipal, 2016).

After officially launching the LEZ policy for high-emission trucks on 21 September 2017 and imposing traffic control on diesel trucks that are non-compliant with the National III emission standards, the LEZ reduced 95 tons of major pollutants from trucks (NOx and PM) based on estimation. However, in the long-term, more steps and investments are necessary to enable electrification of the urban freight sector, particularly heavy-duty vehicles, and innovate the technology to facilitate the transition.

I Table 26. Transport policies

	National policies	Beijing
Main policy	Four Transport Strategy 14th Five-Year Plan (2021 - 2025) Outline for Building China's Strength in Transport 2020 - 2050 National Comprehensive 3D Transportation Network Planning 2021 - 2035	Beijing Urban Master Plan 2016 - 2035 Beijing 14th Five-Year Plan and 2035 Long-term Plans Beijing Transport Development Plan 2004 - 2020 The annual Comprehensive Transport Action Plan 2021
Climate and air quality	President Xi's declaration on carbon peaking 2030 and carbon-neutral 2060 Vehicle emission standards	Beijing Clean Air Action Plan 2013 - 2017 Blue Sky Action Plan 2018-2020
Green mobility	Green Mobility Action Plan 2019 - 2022	Beijing Green Mobility Plan 2010 - 2012 Beijing People-Transport Green Mobility Action Plan 2009 - 2015
Public transportation	Guiding Opinions of the State Council on Giving Priority to the Development of Public Transport in Cities 2012	Beijing Ground Public Transport Network Master Plan (Draft) 2021 (Xinhua Net, 2020c) Beijing Transport Development Plan 2004 - 2020
Smart mobility	Guiding Opinions on Promoting the Construction of New Infrastructure in the Transportation Field 2020	New Generation Smart Mobility Development Plan 2018 - 2020 Smart Mobility Three-Year Action Plan 2019 - 2021
Electric mobility	NEV Industry Development Plan 2021 - 2035	
Urban freight		Beijing Green Freight Development Action Plan 2016 - 2020

Shift to energy-efficient transport modes

Public transportation: The backbone of the sustainable mobility system

Beijing invested over 430 billion CNY (about 67 billion USD) in transportation infrastructure, including 14 subway routes totaling 554 km between 2007 and 2015. The metro system forms the backbone of the public transportation system, with 23 metro lines covering 678 km and 394 stations and a suburban rail network connecting to the Jing-Jin-Ji economic region. It is supplemented by 1,266 bus lines and four bus rapid transit (BRT) corridors. The entire public transport system boasts an average daily ridership of 12.3 million passengers. During the 13th Five-Year Plan period, the metro network coverage increased by 31% to 727 km, 17 routes, and 428 stations by 2020. Aside from expanding the metro network, the city also optimizes the old lines and shortens the departure interval. Beijing aims to achieve 1,600 km of the metropolitan metro network and increase the modal split to 56% by 2025 and no less than 2,500 km by 2035, according to the Beijing City Comprehensive Plan (2016 - 2035).

At the same time, the average daily passenger traffic increased by 19%, from 9.11 million to 10.86 million passengers. The average daily passenger traffic increased by 21%, from 10.14 million to 12.32 million on weekdays. Despite the high passenger capacity, the punctuality rate increased from 99.92% to 99.97%. As part of the COVID-19 safety response, Beijing Metro reduced the waiting period and density by increasing the running interval, achieving 1 minute and 45 seconds for certain lines (Beijing News, 2021). Even as metro ridership increased exponentially, public bus ridership decreased during this period, from 3.626 billion person-times to 3.17 billion person-times between 2000 and 2020 (Figure 34) (Beijing Commission of Transport, 2020).

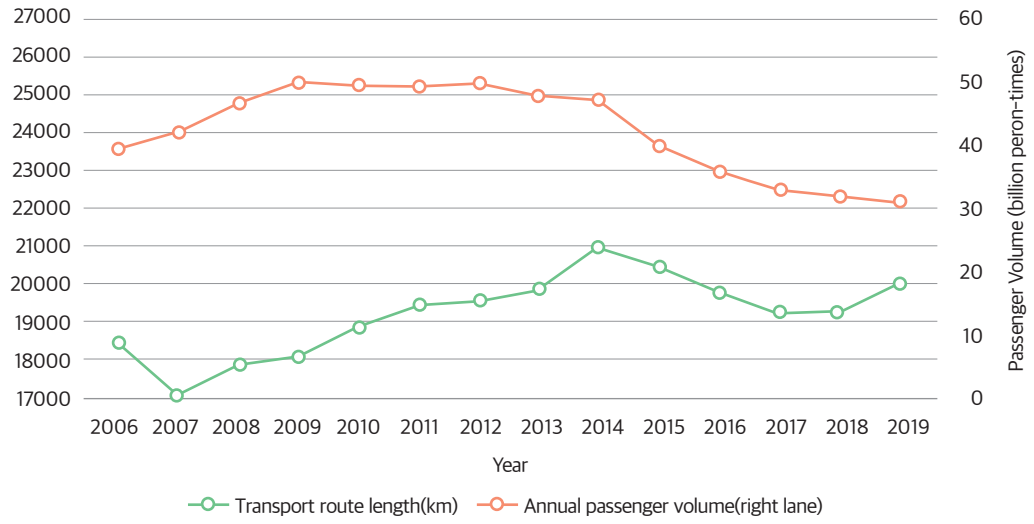
As housing prices are high in Beijing, many commuters live at the periphery of Beijing city. Therefore, suburban metro construction is pivotal in connecting the suburban centers to the urban core as more than 50% rely on metro and buses to travel. In 2020 alone, Beijing constructed four new suburban metro lines and nine new stations totaling 153.9 km (People.cn, 2021).

Besides the metro system, Beijing successively diversified the bus lines and demand-responsive buses to meet the differentiated travel needs. The city maintains 1,158 bus routes with 276,632 km, of which 952-km is reserved for BRT. In response to the COVID-19 pandemic, Beijing upgraded the demand-responsive bus system for online booking to provide safe and convenient travel services through the 223 customized bus routes.

Green Mobility

Walking and cycling are essential aspects of urban commute and critical for the urban mobility system, requiring low investments yet delivering a high return in health and livability. Furthermore, in recent years, Beijing began to realize the importance of social and cultural functions of public space for community interaction and the value of designing cities to reinforce walkable and bikeable cities. As a result, walking and cycling are the primary travel modes in downtown Beijing (74%), and this is correlated with the reduction of peak congestion index within the urban core in 2021.

Within the 13th Five-Year period, 3,200 km of continuous cycling lane within the Fifth Ring Road was completed



I Figure 34. Trend in bus ridership and length in bus route in Beijing

to connect public transportation to active mobility seamlessly. The expansion of the cycling lane is accompanied by the shared bicycle boom, supporting short-distance or last-mile journeys. There are about 900,000 shared bikes in Beijing, although the figure once hit 2.35 million in September 2017, particularly oversaturated at the CBD. The cumulative amount of shared bicycle rides was 690 million in 2020, averaging 1.889 million rides each day. This is an increase of 13.4% compared to 2019 (Beijing Daily, 2021). As a result, BMCT issued the "Internal Bike-sharing Industry Supervision 2020 and Announcement of the Vehicle Scale in 2021" guidance to limit the number of dock-less bikes within the CBD to below 800,000 as of 2021. The quota is distributed between the three major bike-sharing companies: Meituan bike (800,000), Hello bike (210,000), and Qingju bike (190,000) (Beijing Daily, 2021). In addition, Beijing set aside 4,325 parking spots for shared bikes by piloting the electronic fence program to better control parking and urban space. However, as there are issues of sub-standard batteries and complicated operations, Beijing, Shanghai, and Guangzhou cities have temporarily banned the development of electric bike-sharing until further notice.

Bike-sharing altered mobility behavior. 79% of the bike-sharing trips are for commuting to work or school, reflecting the bike-sharing system's potential to reduce the VKT by cars and possibly other public transportation modes. Most carbon emissions are generated during the manufacturing phase from a lifecycle perspective. Therefore, the utilization rate of bikes plays a significant role in increasing the carbon mitigation impacts. However, fewer than 50% of the shared bikes are effectively used, and only half contribute to carbon reduction, according to the Ministry of Transport (2017) (Ministry of Transport of the People's Republic of China, 2017).

Beijing MaaS platform: A multimodal seamless travel experience featuring carbon emission reduction accounting

Mobility-as-a-Service (MaaS) is a mobility ecosystem concept that aims to integrate all transport services and modes in a single mobility platform to provide users with a seamless and accessible travel experience. The National Outline for Building China's Strength in Transport, released in September 2019, emphasized the MaaS development. Beijing developed an online ticketing system or QR code, and such a system achieved almost 70% of the penetration rate. Over 9.2 million users registered for the QR-quick access ticketing system, whereby the same ticketing system in Beijing can be used in Shanghai and other cities for easier access.

In September 2019, the BMCT and the BEE collaborated with Alibaba's AutoNavi Maps and Baidu Maps to launch the Beijing MaaS platform, branded as the "Beijing Green Transportation Integrated Service Platform." The first domestic MaaS platform provides real-time multimodal transportation information for route planning and navigation. The innovative component that differentiates Beijing MaaS from many international MaaS systems is introducing the carbon credit incentive scheme for green mobility to nudge commuters to opt for green mobility travel through this system. Users can earn carbon credit through green mobility travels using AutoNavi or Baidu Maps applications and redeem for rewards.

The Beijing MaaS platform provides integrated travel information of the different transport modes, including bus, metro, suburban rail, walking, cycling, taxi, flight, train, coaches, ride-hailing, bike-sharing, autonomous driving options, and others. Commuters receive comprehensive real-time information on the location of buses, traffic updates and forecasts, congestion of subway stations and carriages, and others. By November 2020, the platform's number of public transportation users exceeded 10 million and the average daily service public transportation trips exceeded 5 million. The real-time bus coverage is more than 95% of the popular bus routes in Beijing, with real-time accuracy exceeding 97%. It is also a demonstration of public-private partnerships in effectively using and sharing big data to provide users with a better travel experience.

Carbon credit accounting and trading

To further expand the MaaS services and encourage behavioral change, the BMCT and the BEE cooperated with AutoNavi and Baidu Maps to launch the "MaaS Travel Green City Initiative" on 8 September 2020, a green carbon credit system on the Beijing MaaS platform to reward commuters using green travel modes*. Participating residents can create a personal carbon credit account on the AutoNavi Maps and Baidu Maps applications. When the carbon credit snowballs, it can be redeemed and used for charities, such as tree planting activities or exchange for public transportation coupons or other rewards in the navigation apps.

AutoNavi Map and Baidu Map applications will collect the redeemed carbon credits and trade them off at the

* Green travel refers to walking, cycling, public transportation and shared mobility

Beijing carbon trading market after reaching a certain threshold and auditing by the relevant authorities (1 gram of carbon credit is equivalent of 1 gram of carbon emission reduced). The carbon credit is determined by the users' travel mileage and transport modes. It is calculated based on the emission factors and requirements stipulated in the "Beijing Low-Carbon Travel Carbon Emission Reduction Methodology (Trial)." The proceeds from the carbon trading market will be returned to users. Furthermore, the MaaS platform also provides users with additional rewards based on their participation level (daily check-ins).

It served about 2.45 million residents within three months with a cumulative green trip mileage of 30 million km and a carbon emission reduction of 8,057 tons (BMCT, 2020), which grew to 46,000 tons as of October 2021 with 14,429 million person-times (Xinhua Het, 2021b). The BMCT is developing a roadmap to integrate more transport modes and operators in the MaaS platform to attract more users to its carbon credit scheme at the Beijing Winter Olympics 2022.

Improve vehicle and fuel efficiency

Electric mobility: Driving a greener future

The Chinese government identified the EV industry as a strategic and emerging industry under the "Made in China 2025" strategy and launched the "Ten Cities, One Thousand Vehicles (TCOTV)" program that catapulted China to be the world's largest EV market in 2015. Beijing is a pivotal player as it aims to have 20% of the vehicles on the road be NEVs by 2025, equivalent to 4 million cars. Besides, China's 13th Five-Year Plan (2016 - 2020) designated EVs that are eligible for public subsidies, including battery EVs (BEVs), plug-in hybrid EVs (PHEVs), and fuel-cell EVs (FCEVs).

Electrifying public transport

China is the world leader in electric public transport, owning 99% of the world's 385,000 electric buses and is expected to almost double by 2025 (UNEP, 2017). As the capital, Beijing formulated ambitious policies to spur industrial and economic growth while capitalizing on reducing energy consumption and emissions. The city focused on using EVs and plug-in hybrid and electric public buses in public transportation. As a result, lower electricity costs balanced infrastructure costs in electric bus lane investment while reducing up to 51% in emissions and 34% in energy use in the bus fleet (Song, Liu, Gao, & Li, 2019). Such practices make practical sense in Beijing, where the city faces enormous air pollution problems.

Beijing Public Transport Group (BPTG) is a state-owned company responsible for road public transportation in Beijing. Under the TCOTV program, the municipal government invested over 1 billion CNY (154 million USD) in purchasing 860 hybrid buses, reducing the average fuel consumption to 30.77 liters/100 km compared to the diesel buses with 39.89 liters/100km. The use of EVs led to a further 22.9% lower average consumption rate. By 2018, almost 7882 public electric buses were operating in Beijing, more than tripled from 2000 public buses in 2015. EVs and NEVs represent 69.07% of the public buses in Beijing (Beijing Public Transport Group, 2018). Most of the market development is focused on BEVs, while FCEVs are still in the initial adoption phase, hindered by the high cost and lack of infrastructure, although this is rapidly changing. As of 2018, Beijing operates five hydrogen buses, accumulating 33,000 km and 10 kg/100 km of fuel consumption. Beijing alone has more public charging points than Germany. In 2019, there were 149 charging stations and 1,070 charging spots (Beijing Public Transport Group, 2018).

System innovation

The transition to electric vehicles results from a series of policy and strategic changes in the central and local governments to incentivize the industry and consumers. Investing in EVs is a strategic policy decision as 31% of $PM_{2.5}$ in Beijing results from motor vehicles, and EVs can reduce carbon emissions by 13 - 68% (Beijing News, 2014). While the EV transition adopts a top-down model and governmental intervention, the policy framework and implementation address both supply- and demand-side policies by incentivizing auto enterprises to manufacture EVs. The demand-side policies encourage consumers to purchase EVs even if the performance was subpar compared to traditional cars at the initial phase. With time, the market mechanism is fundamental to manufacture internationally competitive vehicles.

Beijing Municipal Government is the top policymaker for EVs. The capital works very closely with the central government to jointly define the broad policy framework for long-term investment, research and development, standards, and subsidy policies. While several electric bus manufacturers in China, only two manufacturers produce electric buses in the Beijing public transportation network: the Beiqi Foton Motor Cooperation (Futon) and Zhuhai Yinlong New Energy Co. Ltd (Yinlong). Futon is a state-owned Beijing Automotive Industrial Corporation (BAIC) subsidiary. Charging stations are

a catalyst for developing EVs and electric buses. In Beijing, State Grid and China Potevia are responsible for charging infrastructure: battery swap or battery charging technology. Other stakeholders, including banks, maintenance agencies, universities, are also critical players in the electric mobility ecosystem.

Aside from replacing old diesel buses with NEVs, the expensive and limited land resource is another critical aspect. Therefore, BPTG optimized the bus depot design concept by minimizing the land-use area and optimizing the resources used. For example, the Ertong Factory bus station is about 14,800 $m^{2,}$ but the total usable space is 27564 m^2, offering parking spots for 169 public electric buses, 84 cars, and 20 charging poles. The efficient design saved 81.7% of land resources compared to traditional design. Furthermore, the company aims to reduce the energy consumption in its operations, thereby achieving monthly energy consumption of 0.104 tons of standard coal equivalent/ 100 km (Beijing Public Transport Group, 2019).

Vehicle and emissions control

Vehicle restrictions

Beijing attempted to increase the use of public transport by lowering fares by 60% in 2009. Most public transport fares cost only 0.4 to 2 CNY (less than 0.31 USD), but it did not substantially impact travel habits. Therefore, Beijing city launched the car registration quota system in 2011 and set an initial annual limit of 240,000 (Beijing Municipal Government, 2011). In addition, a lottery system was established for new car buyers to win a license plate and register a vehicle. When the intense urban air pollution swept across China in the winter of 2013, Beijing announced reducing the limit to 150,000 new vehicles, of which 20,000 are NEVs. This is further reduced to 100,000 new vehicles since 2021 as the vehicle population exceeds 6.62 million. The allowance for NEVs increased to 60,000 between 2015 - 2017 while the total number of new license plates remained. The license plate lottery policy proved helpful in vehicle ownership control but had little influence on the travel time or distance. It was estimated that the total number of vehicles in Beijing reduced by about 11% by 2020. Different from Shanghai's auction system in bidding for a license plate, Beijing's lottery does not raise any revenue that could have been allocated to building public transportation. Nonetheless, the control of vehicle ownership proved successful by reducing the annual automobile growth rate per annum to around 2%.

Vehicle emission control

The MEE and the BEE are responsible for vehicle emission control. The MEE promulgates vehicle emission standards, and the State Council issues national fuel quality standards. BEE is considered a forerunner amongst Chinese local governments in mandating stricter vehicle emission standards ahead of the MEE. The "Jing-Jin-Ji" economic region recently adopted the China 6/VI emission standards, one of the world's most stringent emission standards, in April 2020, ahead of the nationwide implementation in January 2021, which was delayed due to the coronavirus outbreak.

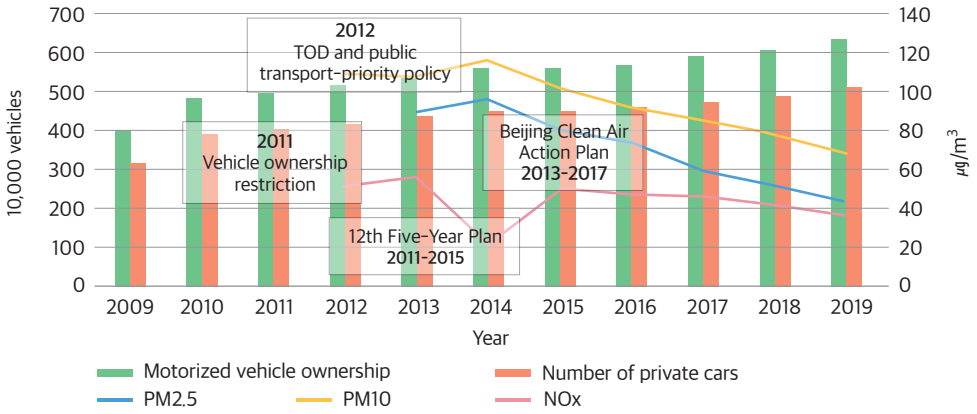
Controls on vehicle use

Beijing controls the final digit of number plates when entering or traveling within the Fifth Ring Road by forbidding them to drive on one weekday per week between 0600 and 2100, proving high effectiveness in emissions control. On average, more than 1 million vehicles are controlled daily, limiting about 120 tons of emissions (BMCT, 2021). Pure EVs are exempted. Parking restrictions and digitalization are used to restrict cars' use and reduce unnecessary circulation. In 2019, Beijing collected 23 billion CNY (3.5 billion USD) from parking, which can be channeled into transport development. Mass scrapping of old vehicles and yellow-labeled vehicles and driving restrictions on light-duty passenger cars on weekdays were also implemented.

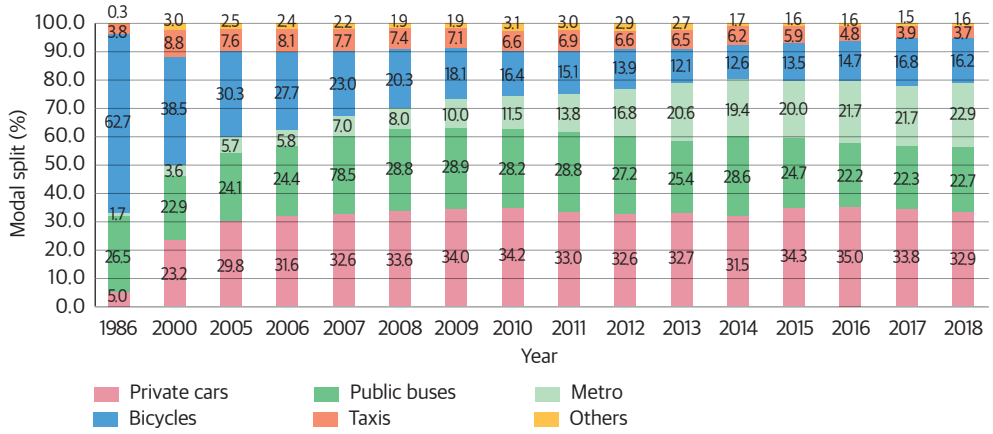
Results and impacts

Through years of TDM and public transport investment, Beijing boasts of one of the world's densest and busiest public transport networks. The speed of automobile ownership decreased dramatically with the annual growth rate for motorized vehicles and number of private cars as 4.6% and 4.8%, respectively, compared to 19.7% and 22.7% in 2010. As of 2019, Beijing's vehicle population reached 6.36 million vehicles. In addition, Beijing reached 99.4% bus station coverage within 500-meter and 952 km bus-only lane, transporting 8.586 million daily passenger volumes. Other significant impacts are (Beijing Transportation Development and Research Center (BTDRC), 2018; BMDRC, 2019).

- Reduction in traffic congestion index to 5.48, signifying mildly congested
- 1350.7 km of the railway line and 62.7% of electrification rate in 2019
- 18.47 billion CNY (2.8 billion USD) of investment in 2019 alone



I Figure 35. Trend in motorized vehicle ownership and key transport-related air pollutant emissions over the years (Data source: BTDRC 2019)



I Figure 36. The trend in the modal split (Data source: BTDRC 2018, 2019)

- 307,000 new energy buses, a 36.6% increase from 2018
- 74.1% green mobility trips done in the city center
- Travel time of 2.17 min/ km for subway; 2.79 min/km for private cars; and 3.53 min/km for public bus, signifying relatively high travel efficiency with the public transport system

The fight for cleaner air shows tremendous results through Beijing's comprehensive and integrated fuel economy and vehicle restrictions policies stipulated in the Beijing Clean Air Action Plan 2013-2017. In almost the last decade, $PM_{2.5}$ decreased more than 53% to 42 μg/m³, while NOx reduced by 29% to 37μg/m³ (Figure 36).

As reflected in the VKT and modal split of daily trips by automobiles, the actual car use also shows a stabilizing and slightly decreasing trend. In contrast, public transportation and cycling represent more than 60% of the trips on average (Figure 36).

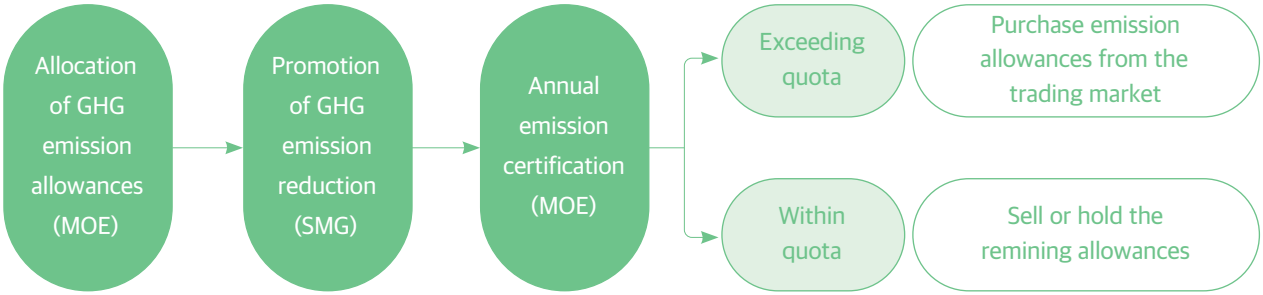
Barriers and challenges

To meet China's decarbonization target, a clear electrification pathway with people-oriented transportation and urban planning needs to be detailed in the medium-term, particularly addressing the urban freight sector as around 32.06 million tons of goods were transported in Beijing. Furthermore, although Beijing pledged to limit population and vehicle growth in the city, the congestion rate is still relatively high, so green mobility and walking policies need to be strengthened to control SOVs.

Lessons learned

Beijing adopts innovative regulatory, market-driven, and transit-oriented approaches to transition to a sustainable, low-emission mobility system. The stringent vehicle fuel efficiency standards NEV policies complementing the vehicle quota system proved effective in controlling vehicle growth rate and transport emissions. However, the piece-meal strategies to limit vehicle use have been more ineffective than the long-term and strategic policies to mainstream public transportation and active mobility.

Beijing could tap into big data analysis to provide better transportation services by working with the private sectors, extending from passenger transport to freight.



I Figure 37. The operation mechanism of the K-ETS (Source: SMG)

The one-of-a-kind carbon credit and accounting is a creative means to address behavioral change while supporting the carbon trading scheme developed by the city. Similar to the electric mobility roll-out, the entire value chain of the electric mobility system is well considered and supported by the different private companies. Such an approach is a prerequisite to a sustainable implementation of electric mobility while capitalizing on the opportunity to upgrade the local economy. Furthermore, as the city is constantly changing and innovating, Beijing swiftly adapts to the market trend and demand by linking the transport demand and supply more closely in policy planning and implementation to reap environmental and livability benefits.

4.2.4 Emission Trading Scheme (ETS)

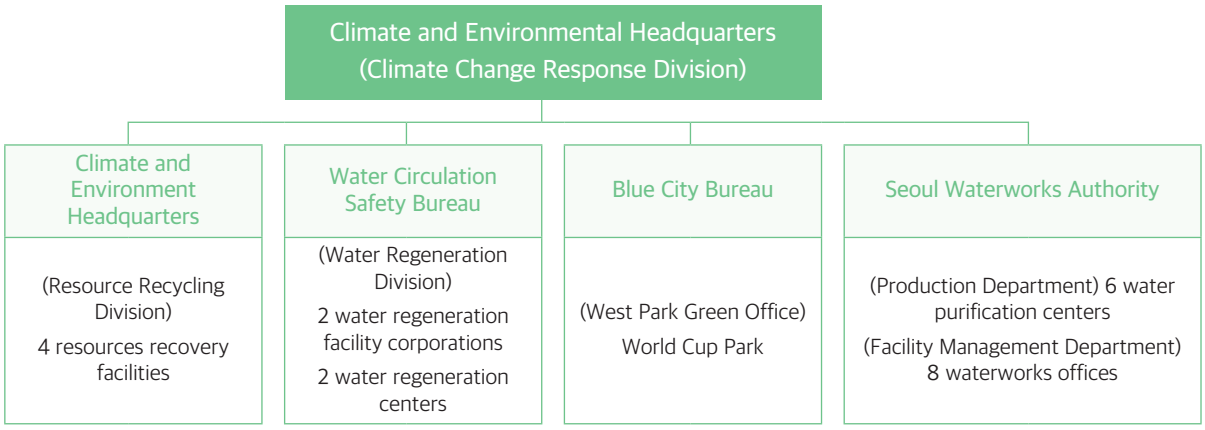
4.2.4.1 Seoul

Korean entities that exceeded the inclusion thresholds* are mandated to participate in the nationwide Emission Trading Scheme (ETS), known as the Korea ETS (K-ETS). Launching on 1 January 2015, it is the first nationwide mandatory ETS in East Asia. The MOE bears the overall responsibility of supervising the K-ETS operation, while the Ministry of Economy and Finance (MOEF) chairs the Allocation Committee (ICAP, 2021). Figure 37 shows the operation mechanism of the K-ETS.

The K-ETS is now in Phase Three (2021 - 2025) with the expanded scope after the initial Phase One (2015-2017) and Phase Two (2018-2020) implementation. In Phase Three, the K-ETS covers six sectors, including heat and power, industry, buildings, transportation, waste, and the public sectors. There are 69 subsectors in total under the six sectors. Regarding the type of regulated GHGs, the K-ETS covers six greenhouse gases: CO_2, CH_4, N_2O, PFCs, HFCs, and SF_6. The K-ETS covers companies emitting more than 125,000 tCO_2e per year and industries emitting more than 25,000 tCO_2e per year. Besides direct Scope 1 emissions, indirect emissions from electricity consumption (Scope 2) are also considered. The K-ETS regulates 686 of the largest emitters, accounting for around 73.5% of the national GHG emissions (ICAP, 2021).

As one of the allocated entities of waste disposal, SMG has been specifically assigned to target 23 basic environmental facilities, including four water regeneration centers, four resource recovery facilities, 14 water supply plants, and the World Cup Park. Figure 38 shows the management mechanism of the 23 facilities. Relevant SMG departments establish and implement GHG emission reduction plans and use state-supported projects to ensure that the facilities fulfill emission reduction responsibilities.

* The inclusion thresholds for companies and facilities are 125,000 tCO_2e per year and facilities emitting 25,000 tCO_2e per year, respectively.



I Figure 38. The management of the K-ETS participating entities in Seoul (Source: SMG)

The K-ETS plays a key role in meeting South Korea's 2030 climate targets and 2050 net-zero commitment. The participating facilities managed by SMG are incentivized to reduce GHG emissions. It is expected that ETS participation of the entities in Seoul is will contribute to achieving the climate targets of Seoul.

4.2.4.2 Beijing

As one of the seven pilots in China, Beijing launched its ETS in November 2013. Since then, Beijing has developed a "1+1+N" policy framework to support the ETS's operation. The first "1" refers to the Decision on Implementing CO_2 ETS in Beijing issued by the Standing Committee of Beijing Municipal People's Congress. The decision is the highest legal regulation related to the operation of Beijing ETS. The second "1" refers to the Interim Measures for the Management of Emissions Trading in Beijing published by the Beijing Municipal Government. Finally, the "N" refers to all the supporting laws and regulations set up to elaborate the measures mentioned above in detail. The policy framework consists of a comprehensive legal and policy basis for the long-term development of the Beijing ETS.

From 2019 onwards, BEE has been the leading supervision office of the Beijing ETS. The China Beijing Environmental Exchange (CBEEX) was appointed as the official trading platform to ensure just, fair, and transparent transactions. The participants of the Beijing ETS include regulated entities, mandatory reporting entities, and individual actors. Regulated entities refer to the entities with more than 5,000 tCO_2 of direct and indirect emissions. Mandatory reporting entities refer to the entities that consume more than 2,000 tce.

Since the official launch in 2013, the trading activities of the Beijing ETS have been steadily increasing in volume and value. In 2020, the Beijing ETS covered 859 regulated entities in eight major sectors, including power generation, petrochemical, cement, and 570 mandatory entities. As a result, the average online transaction price of carbon allowances in 2021 was CNY 72.86 per ton, and the highest reached CNY 107 per ton. By the end of 2021, the cumulative turnover of carbon market allowances in Beijing exceeded CNY 2.21 billion (around USD 334 million).

4.3 Integrated management of climate change and air quality

4.3.1 Seoul

The energy sector is the core of Seoul's integrated management of climate change and air quality. Energy accounts for 91% of the GHG emissions and over 96% of $PM_{2.5}$ precursors, such as NO_x, SO_x, and black carbon (Climate and Environment Headquarters, 2021a). Given the significant role of the energy sector in GHG and air pollutant emissions, carbon neutrality and clean air cannot be achieved without a complete green energy transition.

A representative case of the green energy transition in Seoul is the eco-friendly boiler replacement project. As mentioned above, eco-friendly boilers emit 88% less NO_x compared to regular boilers. The eco-friendly boilers also cause fewer GHG emissions through heat efficiency improvement. Meanwhile, the project also generated financial revenues.

The actions in the transport sector are a critical component of integrated management. For example, the development of LEZ and GTZ contributes to controlling outdated vehicles, and EV promotion supports the clean and low-carbon mobility transition. The transport sector emits fewer air pollutants and GHGs by replacing outdated vehicles with EVs.

Achieving Seoul's 2050 carbon neutrality target will generate multiple co-benefits for air quality. The actions incorporated in the *2050 Seoul Climate Action Plan* can reduce 80% of GHG emissions by 2050 from the 2005 level, while the remaining 20% will be offset. These actions will also enhance air quality by reducing $PM_{2.5}$, NO_x, and SO_x emissions by 50%-60% by 2050 from the 2016 levels, as shown in Table 27.

4.3.2 Beijing

Beijing's clean air actions, especially on $PM_{2.5}$ control, have supported the city's climate change mitigation effort by advancing the low-carbon transition in the last decade. It is anticipated that the city's climate actions towards carbon neutrality will further improve air quality.

I Table 27. Air quality co-benefits from carbon neutrality by 2050 (Source: Climate and Environment Headquarters, 2021a)

Policy	GHG emissions (above 2005 levels)	$PM_{2.5}$ emissions (above 2016 levels)	NO_x emissions (above 2016 levels)	SO_x emissions (above 2016 levels)
BAU	-5%	-16%	-22%	7%
Carbon neutral	-100% (offset included)	-54%	-61%	-59%

I Table 28. The emission reduction of key air pollutants from the energy sector in Beijing (Source: Beijing Municipal Government, 2017)

Emissions (t)	SO_2	NO_x	$PM_{2.5}$	PM_{10}
2010	97,892	68,545	27,886	34,177
2015	47,071	49,347	15,037	19,854
2020	30,171	27,954	7,387	10,120
Reduction in 12th FYP period (%)	51.9	28.0	46.1	41.9
Predicted reduction in the 13th FYP period (%)	35.9	43.4	50.9	49.0

Notes: The energy sector does not include fuels, which are covered in the transport sector.

In 2021, MEE published the *Guidance on Coordinating and Strengthening the Work Related to Climate Change and Ecological Protection*, providing a comprehensive framework for integrated climate change and air quality management. The document confirmed that carbon emission reduction is the core of China's future integrated management actions (MEE, 2021).

Similar to Seoul, the energy sector is also a critical component of Beijing's integrated management of climate change and clean air. Significant actions in the energy sector include coal-to-clean energy transition, energy efficiency improvement, and strengthened emission standards mentioned above. In the 13th FYP period, it is estimated that the direct emissions of SO_2, NO_x, $PM_{2.5}$, and PM_{10} from energy use activities will reduce by 35.9%, 43.4%, 50.9%, and 49%, respectively (Beijing Municipal Government, 2017). Table 28 shows the decreasing trend of key air pollutants to which the energy sector transition makes significant contributions.

Chapter 5

Recommendations

Seoul and Beijing are poised to accelerate the low-emission and inclusive transition towards livable cities with vibrant economies and, while doing so, contribute to global climate change and sustainability. The most substantial enabling factors are the climate action planning as well as the institutional agencies that foster the implementation. Firstly, both cities are committed to achieving carbon neutrality around mid-century. Seoul's *2050 Seoul Climate Action Plan* chartered the transitional roadmap to achieve carbon neutrality by 2050, while Beijing will soon release the *Carbon Neutrality Roadmap*. Secondly, both cities have firm climate departments to lead the climate action plans and coordinate the cross-sectoral strategies and stakeholders, i.e., the Seoul Climate and Environment Headquarters and the BEE. The technical institutions also support making science-based climate action planning. The common mandate that both cities share in addressing climate, environmental, and air pollution goals, signifying the shared aims, approaches, and sectoral strategies in the metropolitan cities. Furthermore, the sectoral priorities in climate actions that both cities undertake have similar focus yet differentiated implementation approaches, which allow for peer learning and partnership developments.

This chapter presents the key messages and policy recommendations for Seoul and Beijing based on the study, although they could also benefit other similar metropolitan cities. Finally, the study concludes with the potential thematic for Seoul and Beijing in future bilateral exchanges.

5.1 Policy recommendations

Recommendation 1:
Spatial planning in managing urban growth and climate-proof cities

Spatial urban and regional planning is increasingly recognized as the core of climate adaptation and mitigation by managing urban growth and the associated climate-related spatial conflicts, vulnerability, and socio-economic impacts. The urban layout and expansion are closely associated with reducing urban energy intensity, climate change adaptation, and urban infrastructure needs. What makes spatial planning even more crucial is the lasting impact that it will bring to cities, preventing lock-in to carbon-intensive or hazard-prone conditions. While both cities have leveraged on Transit-Oriented Development (TOD) to transform the urban mobility systems successfully, the potential of urban planning and design can create low-emission cities and urban districts. For example, the Western Harbor District of Malmö will turn a brownfield into a green, 100% renewable energy-based town.

Recommendation 2:
Integrated climate action for climate-proof cities

Responding to climate change in the urban environment in the urban era requires a three-pronged approach: climate mitigation, adaptation, and resilience. The IPCC stresses that carbon-neutral cities refer to "development trajectories that combine adaptation and mitigation to realize the goal of sustainable development," which is also in line with ICLEI's Climate Neutrality Framework. Currently, the cities' comprehensive climate action plans identified high-impact sectors to drastically reduce emissions, including energy, building, transport, and waste sectors. At the same time, green forests and urban space are seen as carbon sinks. A step further is that both cities can parallelly focus on climate change adaptation and resilience strategies. Even as climate change impacts and risks can be felt in different forms, such as heatwaves, urban flooding risks, water and food security, the climate action planning process can be more linked to adaptation and resilience measures. For example, the Paris climate and energy action plan assumes that cities need to live with climate change and intensifying adaptation strategies is the core to enhance the overall urban resilience.

Recommendation 3:
Sustainable financing and market instruments

Financing climate action is expensive but presents a considerable opportunity for investment and divestment,

particularly private actors. As metropolitan cities and capitals, Seoul and Beijing have the autonomy to budget and finance climate actions., Seoul committed 73.4 trillion KRW (61 billion USD) for the Green New Deal (SMG, 2021d). In East Asia and the Asia Pacific cities, private sectors channel about 187 billion USD annually into urban climate finance, but another 1.4 trillion USD would be needed (Buchner Barbara & Wahba Sameh, 2021). Therefore, cities can leverage economic and market-based instruments to provide better and regulate sustainable financing for climate-smart urban infrastructure. As shown in Beijing's ETS, integrating climate-smart metrics and carbon pricing into the decision-making process can increase revenue and capital investment planning in cities. Furthermore, it sends strong market signals for private sectors to innovate climate-proof infrastructure and businesses. Both cities can also collaborate in making detailed research and exchange on the carbon market and ETS to investigate offset of the residual emissions based on their climate action planning. It is also an opportunity to involve the private sector.

Recommendation 4:
Scale-up and integrate cross-sectoral actions

The sectoral actions implemented in Seoul and Beijing began to improve air quality as both cities suffered from episodes of air pollution, all of which have achieved applaudable outcomes and positive impacts. The measures and actions evolved to maximize climate change responses as the city progresses. Interdepartmental collaboration to facilitate cross-sectoral actions is necessary. For example, transport planning and deployment of EVs are essential, from renewable energy deployment and building codes to scale the initiatives.

Energy transition

Both cities leverage renewable energy development in the energy transition and phasing out of coal or reducing reliance on nuclear energy. There are different affordable renewable energy technologies readily available in the market, and the key is to accelerate the energy transition process. Fiscal measures, such as targeted subsidies and energy pricing, can effectively nudge the market. In terms of energy consumption, electrification can support the scaling of renewable energy to curtail less coal burning even outside of the city's administrative boundaries. There is also a trend in distributed renewable energy technologies to benefit small districts or towns to generate solar PV and combine heat pump solutions with urban sewage and district heating and cooling networks. Aside from clean energy, it supports the cities to be more self-sufficient in energy generation and reduces imported energy.

Greening the building sector

As the building sectors consume high energy demand, the main approaches undertaken by the two cities are remodeling old buildings and designing low-carbon and energy-efficient new buildings by deploying better regulations, subsidies, standards, and technology. Looking at the lifecycle of the buildings, the interventions can be analyzed as follows::

- **Construction phase:** New design methods to improve energy efficiency and decentralized renewable energy use. Beijing uses the prefabricated building to encourage new urban construction methods
- **Operational:** Changing behavior of the residents; and better fiscal measures to incentivize retrofitting of existing or old buildings; standards and certification system has proven useful
- **Decommission:** Sustainable building materials can also be sourced to construct or decommission the building materials more sustainably

Developing a Zero-Carbon Building (ZEB) roadmap is effective for cities to build zero-emission or even energy-positive buildings that are highly energy-efficient and rely only on renewable energy.

Transport and urban mobility

Aside from the carbon neutrality goal, transport is very relevant in air quality management and livability, directly impacting daily livelihood. While both cities have adopted effective "Avoid, Shift, Improve" strategies to reduce automobile ownership and energy intensity, more needs to be done to increase the renewable energy share in the transport sector. Furthermore, the COVID-pandemic-induced freight demand also contributed to increasing GHG emissions. Therefore, working with private sectors is fundamental to support the greening of freight vehicles, particularly large trucks, and caring for the socio-economic factors of freight drivers.

5.2 Recommendations for Seoul-Beijing cooperation

To facilitate fruitful bilateral exchanges between Seoul and Beijing, this section highlights the emerging themes, shared interests, and potential areas for collaboration

based on the research study further to strengthen the metropolitans' commitment to carbon neutrality goals.

The Environmental Division under the Joint Committee has significantly promoted collaboration between the two cities, such as policy dialogues and joint research. Implementation of the carbon neutrality commitment will require collective action and dialogues in terms of policy, technical exchange, and research. To identify potential areas for collaboration, an analysis is done according to the below criteria:

- What are the cities' strengths in planning and implementing carbon neutrality goals?
- What are the city's primary challenges that the bilateral exchange can potentially address?
- What are the synergies and opportunities for bilateral exchange in policy innovation, technical exchange, and bilateral research?

Table 29 shows a rapid gap analysis based on Seoul and Beijing's emerging themes and strategies.

Recommendation 1:
Design integrated and inclusive climate solutions

Although it is lightly addressed, the current research has not focused much on climate resilience and adaptation measures. The cities can collaborate in assessing nature-based solutions (NbS) and integrating biodiversity components into climate action planning and urban planning. As both cities face risks of natural disasters, more studies can be made to assess the cities' climate vulnerability and the necessary adaptation measures, from heat and cold waves to urban flooding. Furthermore, as climate impact affects people differently and both cities face aging population issues, the climate transition needs to be just and inclusive, so assessing the vulnerability from a people-oriented perspective is necessary. Having such an integrated focus may support the city to strengthen its climate action planning and implementation from an integrated perspective, aligned

I Table 29. Gap analysis of the Seoul and Beijing climate action strategies

	Climate st rategies	Climate governance	Energy systems	Low-carbon climate actions
Strengths	• Commitment to carbon neutrality • Solid five-year climate plans • Concrete climate law in Seoul • International climate cooperation experience and capacity • Climate change adaptation plan in Seoul • Strong infrastructure for resilience improvement in Beijing	• Climate policy coordination groups • Climate institutes owning mandates on both climate and environmental protection • Affiliated research institutes supporting science-based solutions •	• Solar energy deployment • Smart energy management system development • Energy efficiency improvement • Regional cooperation on energy import • Strong coal reduction effort in Beijing	• Old building renovation and urban regeneration • ZEB roadmap and demonstration projects in Seoul • Green building and prefabricated building development in Beijing • Building GHG emission cap scheme in Seoul / Energy consumption quota mechanism in Beijing • Building efficiency certification • Long-term mobility policy and consistent implementation • Public transport • Multi-modal transport
Weakness	• MRV mechanism	• Climate budget and innovative financing scheme • Coordination between climate departments and other sectoral departments, such as energy, transport and building	• Dependent on fossil fuels (i.e., oil and gas) • Public engagement in renewable energy deployment • Dependent on imported energy	• Many old buildings • High energy intensity • Relatively small number of EVs and hydrogen vehicles in Seoul • High urban freight • Energy use in transport

with the ICLEI Climate Neutrality Framework. Managing sustainable urban growth is another cornerstone towards low-emissions and inclusive development.

Recommendation 2:
Conduct joint research on MRV systems for climate strategies and projects

Seoul published *the 2050 Seoul Climate Action Plan,* while Beijing will soon publish the carbon neutrality roadmap. There is still a long way to achieve the mid- and long-term transition focus and needs. The two cities need to monitor the progress regularly and update the roadmaps as there will be knowledge and technical breakthroughs or bottlenecks. Meanwhile, as both cities design five-year climate action plans to guide climate efforts, the two cities can discuss how to implement and monitor these climate action plans effectively. Discussing carbon neutrality roadmaps and climate action plans will support the two cities to design their climate strategies better.

Both cities have launched many climate projects, with more to come. An effective MRV system helps cities understand the impact of climate projects and design and select high-impact climate solutions. Seoul and Beijing can research MRV methods and applications. The two cities can further design platforms showing their climate efforts by publishing MRV results. For example, California operates *CoolCalifornia.org*[*], as a one-stop-shop packed with climate tools, and *the California Climate Investments Project Map*[**] shows the project-level information on climate investment using Cap-and-Trade auction proceeds.

Recommendation 3:
Organize exchanges to promote stakeholder collaboration and public engagement

Moving towards carbon neutrality will involve many stakeholders inside and outside the government. For example, reducing GHG emissions of the building sector requires coordination and collaboration with multiple government agencies (e.g., environment, energy, and land-use), enterprises (e.g., material production, architecture, and construction), and the public (e.g., property owners and tenants). While promoting renewable energy, Seoul has already met difficulties in public engagement. With the deepening of carbon reduction actions, the need for coordination and collaboration will only increase. Therefore, Seoul and Beijing can organize regular exchanges to foster coordination and cooperation within the government and public and private sectors.

Recommendation 4:
Explore cooperation opportunities on climate finance-related actions, such as climate budget, carbon tax, and emission trading

Realizing carbon neutrality requires enormous investment. The two cities can explore cooperation on how to boost climate finance. The two cities can discuss various policy instruments on climate finance, such as climate budget and carbon tax. Firstly, traditional budget management systems limit the synergizing effect of climate projects and other projects. Some cities like Oslo[***] have launched climate budgets as a governance tool. Secondly, current carbon tax systems are incompatible with carbon neutrality targets if one exists. The two cities can discuss designing effective and fair carbon tax systems at the local level. The revenues from the carbon tax system can be invested in climate projects. Thirdly, Beijing has gained abundant experience on ETS and the carbon credit and accounting system within the transport sector.

Recommendation 5:
Conduct joint research on demand-side management

Both cities have invested significant resources in supply-side policies, such as renewable energy deployment and EV promotion[****]. However, demand-side management to promote behavioral change is equally pivotal. Behavioral change might be the most challenging as it involves changing lifestyles to reduce climate impact, such as cycling to work instead of driving, turning down the heat, or holidaying closer to home. These small changes together will make a big difference in GHG emissions. Therefore, Seoul and Beijing need to promote behavioral changes through demand-side management to avoid energy-intensive lifestyles. Conducting joint research on demand-side management in specific areas will support the two cities' capacity on demand-side management.

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* https://coolcalifornia.arb.ca.gov/

** https://webmaps.arb.ca.gov/ccimap/

*** https://www.klimaoslo.no/2019/10/29/the-climate-budget-for-dummies/

**** One-off events, like purchasing EVs, are not considered as behavioral change.

Recommendation 6:

Establish thematic working groups on technical innovation and promotion

Given the limits of current technologies, technological breakthroughs are necessary to realize carbon neutrality. As elsewhere in the world, both cities face limitations caused by technology bottlenecks, such as carbon removal, power grids, and building efficiency. Seoul and Beijing both have strong R&D capacities to achieve such breakthroughs, also enabled by the vibrant innovation by the private sectors as the capital. The two cities can specifically establish working groups to drive technological innovation and advancement. Some key low-carbon technologies the two cities can work on include:

- ***Carbon capture and storage (CCS)***. Both cities' energy systems rely on fossil fuels, and fossil fuel-fired infrastructure is expected to play a role in the future energy mix. Thus, CCS will be necessary to remove emissions from the fossil fuel-fired infrastructure.
- ***Smart grids and energy storage.*** Both cities aim to deploy more renewable energy, which will require innovation in power grids and energy storage. Decentralizing small grids and renewable energy in local communities or neighborhoods can strengthen renewable energy deployment too.
- ***ZEB or ultra-low energy consumption buildings***. Both cities will need to cut emissions of the building sector, especially old buildings. ZEB and ultra-low energy consumption buildings are future directions to decarbonize buildings.
- ***Green hydrogen or other low-carbon fuels***. Green hydrogen and other low-carbon fuels are essential to decarbonize the transport sector (e.g., heavy-duty trucks) and energy (e.g., dispatched power generation). Both cities have already issued plans to develop hydrogen technology.

The two cities can also exchange on how to promote clean technology. However, technology is just a part of the system as deploying new technologies often faces barriers, such as high cost and lack of knowledge when they first enter the market. Therefore, discussing such innovation from the systems perspective to look at the appropriate business models, policy support, and implementation mechanisms to support emerging clean technology.

Seoul and Beijing are both leaders in local climate action in many aspects. Achieving carbon neutrality will contribute to a climate-safe and prosperous future for their residents and provide invaluable insights for local decision-makers worldwide. Just as the two cities successfully combat air pollution together, the two cities can realize an inclusive and carbon-neutral future.

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출판물명 서울-베이징 2차 공동연구보고서
발행일 2022년 4월 초판 1쇄 발행
저자 서울특별시 환경정책과; 이클레이 동아시아본부
발행인 서울특별시장 오세훈
발행처 서울특별시 환경정책과
주소 서울특별시 중구 덕수궁길 15
전화 02)2133-3518
디자인 ㈜참착한디자인
인쇄 ㈜참착한디자인
가격 비매품
ISBN 979-11-6599-639-0 95530

출판일련번호 기후환경 411-0023

Seoul-Beijing Bilateral Research Report 2022

비매품/ 무료

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ISBN 979-11-6599-639-0