Future Cities Advisory Outlook 2023

Digital Innovations Empower Urban Net-Zero Carbon Transition

UN-Habitat China Future Cities Council Annual Report 2023

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Preface

Wang Shi
Chair of UN-Habitat China Future Cities Council
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On Earth, no individual or city can escape the impact of climate change. Key indicators such as greenhouse gas concentrations, rising sea levels, ocean heat, and acidification are continuously deteriorating, posing ongoing obstacles and harm to global sustainability and ecosystems, particularly in urban areas.

Currently, over 50% of the global population resides in cities, and it is projected that, by 2050, urban populations will constitute around 68% of the world's population. Cities contribute to 80% of the global GDP but also generate 70% of the world's energy consumption and greenhouse gas emissions. Cities are both the source of problems and the key to solving them, making them indispensable in achieving net-zero carbon goals.

Digital innovations present a tremendous opportunity for cities to achieve net-zero carbon. Technologies such as big data, artificial intelligence, blockchain, and digital twins have made significant achievements in realizing dual carbon goals, playing unique roles in areas like path planning, practices, data monitoring, calculation, feedback, and evaluation. Moreover, digital technologies can effectively facilitate the coordination of urban energy supply and consumption, promote clean energy, innovate energy models, foster new formats, encourage green consumption, and enhance the efficient management and provision of urban services. These innovative digital solutions synergistically reduce emissions, improve energy efficiency, and enhance resilience, thus realizing a net-zero carbon future for cities.

To summarize and share China's experiences in leveraging digital innovation to drive urban net-zero carbon transition, UN-Habitat China Future Cities Council, through a year-long collaboration with city governments, tech companies, research institutions, foundations, and high-level forums, has compiled this report.

The report illustrates the digital technology mapping employed in urban net-zero carbon transition, proposes a roadmap for cities to embrace a net-zero carbon future through digital innovation, showcases ten good practices, and initiates the "Global Urban Digital Net-Zero Carbon Action" initiative. This report provides comprehensive theoretical knowledge and practical cases for global cities undertaking net-zero carbon construction through digital innovation. We anticipate that this report will positively influence global urban transitions towards net-zero carbon.

October 2023

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Contents

01 Introduction

1.1 Climate Change: One of Three Global Crises 03
1.1.1 The Global Impact of Climate Change 04
1.1.2 Impact of Climate Change on China 10
1.1.3 Necessary Actions on Climate Change 12

1.2 Importance of Urban Net-Zero Carbon Transition 16
1.2.1 Goals and Pathways for Urban Climate Change Resilience 17
1.2.2 Global Cities' Actions on Climate Change 17
1.2.3 Chinese Cities' Action on Climate Change 23
1.2.4 The Challenge of Urban Net-Zero Carbon Transition 26

1.3 Opportunities Arising from Digital Development 26
1.3.1 Global Development and Trends in Digital Technology 29
1.3.2 Digital Technology Facilitate Urban Net-Zero Carbon Transition 31

02 Digital Innovations for Net Zero Carbon Cities

2.1 Building & Housing 36
2.1.1 Energy Management in Design, Construction and Operation Stage 36
2.1.2 Smart Heating/Cooling Supply 37

2.2 Urban Water 38
2.2.1 Water Resource Allocation 38
2.2.2 Operation and Maintenance of Water-Supply Networks 39
2.2.3 Wastewater Treatment 39

2.3 Urban Mobility 40
2.3.1 Transport Management 40
2.3.2 Smart Charging System 40

2.4 Urban Waste and Circularity 40
2.4.1 Waste Recycling 41
2.4.2 Waste Sorting 41

2.5 Urban Energy 41
2.5.1 Smart Grid 41
2.5.2 Energy Internet (Internet of Energy) 42

2.6 Carbon Management 42

2.7 Summary 42

03

Digital Innovation Enabling Net Zero Carbon City Roadmap

3.1 Mastering Carbon Data 48
3.1.1 Building the Carbon Data Base 48
3.1.2 Building City "Dual Carbon" Brain 55
3.1.3 Promoting Green Data Centers 56

3.2 Formulating Carbon Strategy 59
3.2.1 Building a Carbon Management Feedback Loop 59
3.2.2 Making Strategy Base on Local Conditions 60
3.2.3 Adhering to a Holistic View and Handling the "Four Relationships" 62

3.3 Smart Carbon Action 63
3.3.1 Energy 63
3.3.2 Urban Transportation 65
3.3.3 Buildings 66

3.4 Summary 74

04

Case Study

4.1 Urban Cases 76
4.1.1 Shanghai Zhenru Sub-Center: Zhenru Jing Project and Haina Engineering Institute Project - Digital Innovation Empowering Net Zero Carbon in Buildings 76
4.1.2 Wuhan: Urban Ventilation Cooling and Low-Carbon Practices 77
4.1.3 Shenzhen: Yantian District's Digital Energy Community Carbon Reduction Practice 80
4.1.4 Chengdu High-tech Zone: Mega-City Carbon Reduction and Pollution Reduction Collaborative Efficiency Management Project 83
4.1.5 Weihai: Digitally Empowering the Development of Red Property 85

4.2 Enterprise Case 87
4.2.1 Xinchao Media: Application of Low-Carbon Elevator Smart Screen in Urban Warning Information Broadcasting 87
4.2.2 BOE Technology Group Co., Ltd.: Application of Smart Windows in Urban Carbon Reduction 89
4.2.3 BYD Co., Ltd.: Application of New Medium and Low Volume Rail Transit System in Urban Carbon Reduction 90
4.2.4 DiDi: Digital Mobility Platform Facilitating Urban Net Zero Carbon Transition 92
4.2.5 Midea Building Technology: Application of Comprehensive Carbon Reduction Governance Solution in Digital Transformation of Industrial Parks 94

05

Recommendations

5.1. Urgency of Global Actions on Climate Change 99

5.2. Leveraging Digital Technology in Urban Net-Zero Carbon Transition 101
5.2.1 Achieving Urban Net-Zero Carbon Transition as a Key Action in Urban Warning Information Broadcasting 103
5.2.2 Digital Technology as a Key Path to Achieving Urban Net-Zero Carbon Goals 104
5.2.3 Digital Technology Facilitating the Carbon Reduction Tools in Industries 105
5.2.4 Managing the Carbon Footprint of Digital Systems 107

5.3 China's Urban Initiatives and Global Collaboration 108
5.3.1 China's Urban Practices in Net-Zero Carbon Transition 108
5.3.2 Deepen International Exchanges and Cooperation 110

5.4 Global Urban Digital Net-Zero Carbon Action Initiatives 113

Key Findings and Messages

UN-Habitat China Future Cities Council was initiated and established by the UN-Habitat China Office. It collaborates with tech companies, city governments, research institutions, foundations, and high-level forums, aiming to leverage advanced smart urban technologies to support urban sustainable development. It is dedicated to leveraging advanced smart urban technologies to support urban sustainable development, promote the implementation of the UN 2030 Sustainable Development Agenda and the New Urban Agenda. This report represents the third annual report.

The report focuses on the major challenges facing global climate actions. In Chapter 1, the report analyzes the impact of climate change on global and Chinese cities. It highlights the significant opportunities presented by the development of digital technology to achieve net-zero carbon cities. Subsequently, Chapter 2 delves into the empowerment of net-zero carbon city construction in six scenes: urban construction and housing, urban water use, urban transportation, urban energy, and urban solid waste management and carbon management.

Chapter 3 focuses on exploring the construction of a digital innovation-assisted roadmap for urban net-zero carbon transition. In Chapter 4, the report provides detailed cases of Chinese cities and enterprises, offering strategic approaches for global urban development towards net-zero carbon transition. In Chapter 5, development suggestions for global net-zero carbon city construction are presented, along with the initiation of a Global Urban Digital Net-Zero Carbon Action initiative.

Chapter 1 Introduction

Advancing the realization of the "Dual Carbon" goals has become a global consensus. Approximately 120 countries have committed to achieving "carbon neutrality" by 2050, with some developed countries and small and medium-sized economies, mainly in the service sector, having already reached "carbon peak." In November 2022, the 27th Conference of the Parties to the United Nations Framework Convention on Climate Change (COP27) called for the transition of commitments into concrete actions to collectively address climate change challenges. However, the world still faces severe climate change challenges, including greenhouse gas emissions, rising sea levels, warnings about ocean conditions, impacts from the COVID-19 pandemic, geopolitical issues, and energy crises affecting climate action. The challenge of achieving urban net-zero carbon is urgent, but global progress in energy transition is limited, and efforts in climate change adaptation planning and support are insufficient.

The development of digital technologies such as big data, artificial intelligence, and 5G provides opportunities for countries worldwide to undergo digital transition, facilitating the advancement of the digital economy and governance models. The key to achieving the "Dual Carbon" goals lies in addressing the uncertainties in economic activities and emission reduction paths. Digital technology can overcome issues of information asymmetry, inadequate data, and insufficient predictive capabilities, providing full-cycle support for carbon optimization, management, and trading. It helps match supply and demand and ensures efficiency in supporting urban net-zero carbon transition.

However, digital technology faces critical challenges in addressing climate change, including fragmented applications, lack of global coordination, digital divides, data privacy and security, and the high carbon emissions associated with digital infrastructure. Effectively promoting the transition and operation of net-zero carbon cities has become a crucial current issue.

1. Impact of Climate Change on Global Cities:

Excessive emissions of greenhouse gases lead to global climate change, causing problems such as rising sea levels, ocean warming, and freshwater loss. This results in severe challenges at social, economic, and ecological levels, including:

a. Reduced habitable areas, human migration, and conflicts.

b. Shortages of food and water resources, leading to famines and conflicts.

c. Ecosystem destruction and a decrease in ecosystem productivity.

d. Loss of freshwater reserves, creating survival challenges for humans, animals, and plants.

e. Disease and pest infestations leading to reduced food production, affecting agriculture and the survival of impoverished populations, ultimately causing social disorder, environmental degradation, and economic decline.

2. Strategies and Methods for Urban Climate Change Resilience:

a. Carbon Reduction Strategy:

Reducing urban energy consumption in spatial planning and construction, including comprehensive and inclusive land-use planning and decision-making. This involves improving the balance between work and residence through regional adjustments and achieving a compact urban form. Strategies include strengthening public transportation systems, guiding green travel, and advocating for digital remote work to reduce transportation-related carbon emissions. Additionally, efficient design, construction, retrofitting, and use of buildings are essential.

Clean energy and industrial economic transition, such as adjusting energy generation and heating structures, upgrading and transforming high-energy-consuming industries, building a low-carbon industrial system, promoting green and circular economies, and promoting the use of new energy vehicles in urban transportation.

Strengthening carbon absorption and storage in the urban environment through blue-green infrastructure. This includes increased investment and construction of urban ecological networks, combining blue-green infrastructure with traditional gray infrastructure, and reducing the risks of extreme events such as heatwaves, floods, heavy rainfall, and droughts. These efforts also generate common benefits for health, well-being, and livelihoods.

b. Goals and Paths for Urban Climate Change Resilience:

Establishing urban carbon reduction goals and clarifying the priority of reduction. These goals should be based on scientific foundations, considering the specific conditions and resource availability of the city to ensure feasibility and sustainability.

Seeking the establishment of a global urban cooperation platform to promote technological sharing and experience exchange among cities. This cross-city collaboration helps accelerate the dissemination of carbon reduction technologies and strategies, enhancing the synergistic effects of global cities in climate action. Simultaneously, building a green humanistic value system is crucial, shaping environmental awareness and sustainable lifestyles among urban residents, further reducing carbon emissions.

Urban carbon reduction actions require clear action paths and systematic measures. This includes improving urban infrastructure, promoting clean energy, implementing carbon pricing policies, encouraging green transportation, and urban greening efforts.

Digital Technologies Empower Urban Net-Zero Carbon Transition:

- Developing new energy technologies to improve energy efficiency and reduce greenhouse gas emissions.

- Activating urban infrastructure to facilitate precise governance and enhance the efficiency of public services.

- Guiding green lifestyle values, promoting public participation, and anchoring ecological humanistic awareness.

- Promoting the development of green finance, creating green products, driving the development of a low-carbon economy.

- Driving innovative business models, encouraging green consumption, and achieving the takeoff of a zero-carbon economy.

Chapter 2: Digital Innovation Empowering Net-Zero Carbon Cities

This chapter outlines the panoramic view of how digital innovation, serving as the foundation, supports net-zero carbon cities in six urban scenarios: urban construction and housing, urban water management, urban transportation, urban waste and recycling, urban energy, and carbon management. Using these scenarios as dimensions, the chapter illustrates how digital technology, in the context of building and housing, facilitates the entire life cycle, particularly in the operational phase for heating and cooling, achieving reductions in consumption and carbon emissions.

In the urban water management scenario, digital technology regulates water resource allocation, optimizes the operation of water supply networks, and enhances the efficiency of wastewater treatment processes to reduce carbon emissions. In the transportation scenario, the focus is on improving transportation efficiency and promoting carbon reduction through the development of new energy transportation infrastructure. In the waste and recycling scenario, establishing incentive mechanisms and increasing the efficiency of recycling processes are highlighted to decrease energy consumption. For urban energy, the chapter emphasizes enhancing the efficiency of traditional energy functions, addressing the integration and stability issues of clean energy, and promoting net-zero carbon city construction from an energy supply perspective.

Chapter 3: Roadmap of Digital Innovations Empowering Net-Zero Carbon Cities

The roadmap for achieving net-zero carbon in cities, referred to as the "carbon-neutral" urbanization roadmap, is a dynamic balancing act between carbon sources and sinks. Therefore, the net-zero carbon city roadmap should be a comprehensive set, systematically addressing the dynamic factors of energy-saving and carbon reduction technology implementation, implementation costs, negative carbon technologies, and forest carbon sink levels. Leveraging digital innovation technologies such as the Internet of Things (IoT), big data, cloud computing, and artificial intelligence (AI), the roadmap is constructed through a three-step process of "mastering carbon data - formulating carbon strategies - implementing smart carbon actions." This aims to propel urban digitization, greenification, and sustainable development, ultimately achieving the goal of "carbon neutrality."

Mastering Carbon Data: By establishing the foundation of urban carbon data, real-time carbon emission data collection is facilitated using big data and IoT technologies. This involves precise accounting and traceability. Scientifically sound perspectives on carbon accounting and emission collection methods are chosen to accurately calculate the carbon footprint of various basic carbon emission units within the city and their transboundary carbon footprints. With data support, a "dual carbon" brain is created, utilizing AI technology to model emission data. This assists relevant urban decision-makers in formulating timely and efficient strategies for managing urban carbon emissions, enhancing the overall systemic efficiency of various sectors within the city.

Formulating Carbon Strategies: Exploring optimal urban carbon strategies involves seeking a dynamic balance among energy, environment, economy, and society to drive long-term sustainable development. Supported by digital technology, the goal is to construct a city carbon management positive feedback closed-loop mechanism and model. This targets the coordinated development of various aspects, including energy, industry, development patterns, pollution control, resident health assurance, and social livelihood. Additionally, on the front of "dual carbon" development policies, a nationwide coordination is sought to form a collective force for systematic carbon reduction, addressing the complexity and diversity of the "peak carbon" and "carbon neutrality" targets. Emphasis is placed on maintaining a systemic perspective and effectively managing the relationships between development and emission reduction, overall and local considerations, long-term and short-term goals, and government and market dynamics.

Smart Carbon Actions: Lastly, digital technology-enabled smart carbon actions in the energy, construction, and transportation sectors are implemented to actualize the city's goals of carbon reduction, new energy substitution, and carbon sequestration, ultimately achieving net-zero carbon urbanization.

Chapter 4: Case Studies

This chapter, following the six major urban energy consumption scenarios outlined in Chapter 2, covers various aspects such as urban planning, city construction, urban transportation, community involvement, and more. It provides five city and five enterprise case studies, offering Chinese strategies and solutions for global cities to promote urban net-zero carbon transformation through digital innovation.

City cases include smart and innovative urban planning solutions such as the Zhenru Jing Project and the Haina Engineering Institute Project in Shanghai: Digital Innovation Empowering Building Net-Zero Carbon and Wuhan: Urban Ventilation and Cooling Low-Carbon Practice. District-wide carbon reduction management innovations include Shenzhen: Yantian District Digital Energy Community Carbon Reduction Practice and Chengdu High-tech Zone: Large-scale Urban Carbon Reduction and Pollution Control Collaborative Efficiency Enhancement Scheme. There are also community management innovations such as Weihai: Digitally Empowering Urban Property Development.

Enterprise cases cover Xinchao Media Group, focusing on urban building energy conservation and multifunctional empowerment: Application of Low-Carbon Elevator Smart Screens in Urban Warning Information Release; BOE Technology Co., Ltd.: Application of Smart Windows in Urban Carbon Reduction; and Midea Building Technology: Application of Comprehensive Carbon Reduction and Governance Solution in the Digital Transformation of Park Areas. For urban transportation research, there's BYD Group: Application of New Medium-Low Capacity Rail Transit System in Urban Carbon Reduction and Didi: Digital Mobility Platform Assisting Urban Transportation Net-Zero Carbon Transformation.

Chapter 5: Recommendations

China actively responds to global carbon reduction goals, combining digital means to take a series of carbon reduction measures. It has formulated specific and efficient implementation paths in policy, finance, industry, and technology. Chinese cities will collaborate with global counterparts to advance urban net-zero carbon transformation goals, propelling cities towards a more sustainable, low-carbon future.

1. Digital Technology Empowering Industry to Form Carbon Reduction Tools

Digital technology plays a crucial role in helping various industries achieve net-zero carbon goals, primarily through three aspects: digitized information, digitized processes, and digitized products.

Digitized Information

a. Data Collection and Analysis: Digital technology assists cities in collecting extensive environmental data, including energy usage, traffic flow, pollution levels, etc. This data enables precise analysis of carbon emission sources, aiding in the formulation of accurate carbon reduction strategies.

b. Intelligent Sensors and Monitoring Systems: Digital technology allows cities to deploy intelligent sensors and monitoring systems, continuously tracking energy consumption, air quality, traffic flow, etc. This information can be used to adjust the use of city equipment and resources in real-time, reducing carbon emissions.

c. Simulation and Predictive Analysis: Digital technology enables cities to build models and simulations to predict the effects of different carbon reduction measures. This helps city planners choose the most effective strategies to minimize carbon emissions.

Digitized Processes

a. Smart Urban Planning: Digital technology assists urban planners in designing more carbon-efficient city layouts, including reducing commuting distances, providing green spaces, and optimizing public transportation systems.

b. Energy Efficiency: Digitized processes help city managers optimize energy use, including energy-efficient building design, automatic adjustment of lighting systems, and smart power grid management.

c. Supply Chain Optimization: Digitized processes can improve the sustainability of the supply chain, reducing energy waste in transportation and warehousing and minimizing the carbon footprint.

Digitized Products

a. Renewable Energy: Digital technology helps improve the efficiency and production of renewable energy, such as solar and wind power. Digital monitoring systems ensure the maximum utilization of these resources, lowering carbon emissions.

b. Smart Buildings: Digitized products include smart building technologies, such as intelligent lighting, smart HVAC systems, and energy management systems, significantly reducing building energy consumption.

c. Electric Transportation: Digital technology drives the development of electric vehicles, which can substantially reduce carbon emissions, especially when charged using renewable energy sources.

2. Chinese Cities Deepen International Exchange and Cooperation

a. Deepening Climate Change Communication:

- Climate change response becomes a diplomatic highlight.
- Promoting high-level dialogue exchanges to consolidate political consensus.

b. Advancing Multilateral Climate Change Negotiations:

- Actively participating in international negotiation processes, including the Convention and its Paris Agreement.
- Actively participating in non-conventional negotiation processes to promote multilateral climate

processes.

c. Strengthening Practical Cooperation on Climate Change:

- Deepening bilateral and multilateral cooperation mechanisms in the climate field.
- Making new progress in South-South cooperation.
- Collaboratively building the "Green Silk Road."

3. Global City Digital Net-Zero Carbon Action Initiative

a. Elevating Urban Management with a Digital Mindset, Implementing Carbon Reduction Actions comprehensively.

b. Utilizing Digital Technology to Promote Energy Transition, Effectively Reducing Greenhouse Gas Emissions.

c. Strengthening International Cooperation with Digital Platforms to Jointly Address Global Climate Change.

d. Driving Public Participation with a Digital Culture, Nurturing the Development of Green Humanistic Values.

e. Promoting Green Consumption through Digital Finance, Driving Innovative Low-Carbon Economic Development.

Figure: Wind Energy Source: Pexel.com

Introduction

The global consensus on the "dual-carbon" goal is now widespread, with approximately 120 countries committing to achieve "carbon neutrality" by 2050. COP27 in 2022 underscored the imperative to translate commitments into actions, with a specific focus on mitigating warming, climate financing, and green development. Despite these efforts, the world continues to grapple with climate challenges, including greenhouse gas emissions, rising sea levels, and alarming ocean conditions. Factors such as the COVID-19 pandemic, geopolitical tensions, and energy crises further complicate climate action. As populations, GDP, carbon emissions, and energy demands surge, the urgency of achieving net-zero carbon cities becomes particularly pressing.

01

Chapter 1

Summary

The global consensus on the "dual-carbon" goal is now widespread, with approximately 120 countries committing to achieve "carbon neutrality" by 2050. COP27 in 2022 underscored the imperative to translate commitments into actions, with a specific focus on mitigating warming, climate financing, and green development. Despite these efforts, the world continues to grapple with climate challenges, including greenhouse gas emissions, rising sea levels, and alarming ocean conditions. Factors such as the COVID-19 pandemic, geopolitical tensions, and energy crises further complicate climate action. As populations, GDP, carbon emissions, and energy demands surge, the urgency of achieving net-zero carbon cities becomes particularly pressing.

China has set ambitious targets with the "2030 carbon peaking" and "2060 carbon neutrality" goals, implementing multi-sectoral policies to actively pursue these objectives. However, challenges stemming from industrialization, resource structures, economic disparities, and technological hurdles necessitate an adaptive, high-quality, and innovative "dual-carbon" approach tailored to the national context.

Digital technologies, including big data, artificial intelligence, 5G, the Internet of Things (IoT), cloud computing, and blockchain, play a crucial role in realizing the "dual-carbon" goals. They can optimize carbon management, enhance energy efficiency, facilitate intelligent resource allocation, promote clean energy adoption, and support the development of ecological monitoring, carbon capture, and trading markets, fostering the advancement of negative carbon technologies. The integration of digital technologies enables the precision governance of cities, promoting the construction of net-zero carbon cities. The Chinese government has already incorporated digitization into its national strategy, making notable progress in areas such as new energy vehicles, smart charging, and urban digitization.

Key words: *Digital technology, city, dual-carbon/Net-Zero Carbon transition, climate change*

1.1 Climate Change: One of Three Global Crises

Global climate change refers to significant and sustained alterations in the statistically averaged climate state on a global scale over an extended period. Throughout Earth's geological history spanning approximately 4.6 billion years, the climate has undergone notable variations, with drastic changes leading to mass extinctions of flora and fauna. Roughly ten thousand years ago, following the conclusion of the last ice age, the Earth's climate stabilized to the familiar conditions for human habitation. However, fluctuations in climate during this period continued to trigger global climate disasters, resulting in substantial casualties and socio-economic losses. An example of such a historical climate catastrophe is the Little Ice Age, which began in the 13th century, peaked in the 17th century, and gradually subsided about two centuries ago. During its zenith, severe cold led to the widespread death of plants and animals. Plunging temperatures also caused crop failures, leading to social unrest and frequent conflicts, with ice and snow spreading globally, causing famine in the Nordic region, where half of the populations of Norway and Sweden perished in the famine.

The causes of climate change may stem from natural internal processes or external forcings, including sustained anthropogenic alterations to atmospheric composition and land use. Following the Industrial Revolution, escalating human activities led to a dramatic increase in emissions of carbon dioxide and other greenhouse gases, disrupting the Earth's long-standing climate equilibrium. The intensification of the "greenhouse effect" has resulted in a continual rise in global temperatures. Today, climate change is considered one of the three global crises, alongside "loss of biodiversity" and "global inequality." In 2018, the Intergovernmental Panel on Climate Change (IPCC) issued a significant warning: "Global temperature increase must be limited to 1.5 degrees Celsius, or the Earth will face catastrophic climate consequences after 2030."

Figure 1-1: UN climate action: the path to net zero emissions
Source: https://www.un.org/sites/un2.un.org/files/2021/04/timeline_2020.jpg

1.1.1 The Global Impact of Climate Change

As mentioned above, the Industrial Revolution has intensified global population growth, exacerbating carbon dioxide emissions and climate change due to industrialization and urbanization. Climate change has had profound adverse effects on a global scale, with relevant data indicating a 1.1-degree Celsius increase in global temperatures since the Industrial Revolution. In less than 200 years, human activities have increased the atmospheric carbon dioxide concentration by 50%, reaching 421 parts per million. Greenhouse gases in the atmosphere contribute significantly to global warming, being a primary driver of climate change. Furthermore, methane concentration in the atmosphere has more than doubled over the past 200 years, reaching 1923.6 parts per billion. This growth is estimated to account for 20% to 30% of climate warming since the Industrial Revolution.

Continued global warming has led to the deterioration of human habitats, becoming a shared global issue, particularly impacting developing countries and coastal cities. Due to anthropogenic global warming, the global sea level is rising and has currently reached 99 (±4) millimeters. The recent rate of rise is unprecedented in over 2500 years, with a 10-centimeter increase in the global average sea level compared to 1993 and a 21-24 centimeter rise compared to 1880. Additionally, the probability of flooding caused by storm surges has increased by 3 to 9 times compared to 50 years ago. The ongoing rise in sea levels poses a serious threat to many coastal and island cities. Notably, 8 out of the world's 10 largest cities are coastal, making them highly vulnerable to rising sea levels. Over the past 20 years, Venice, a cultural treasure of human history, has experienced 166 instances of high tides, with rising sea levels damaging its structures, eroding foundations, and creating structural risks. In the worst-case scenario, Venice could disappear beneath the sea by as early as 2100.

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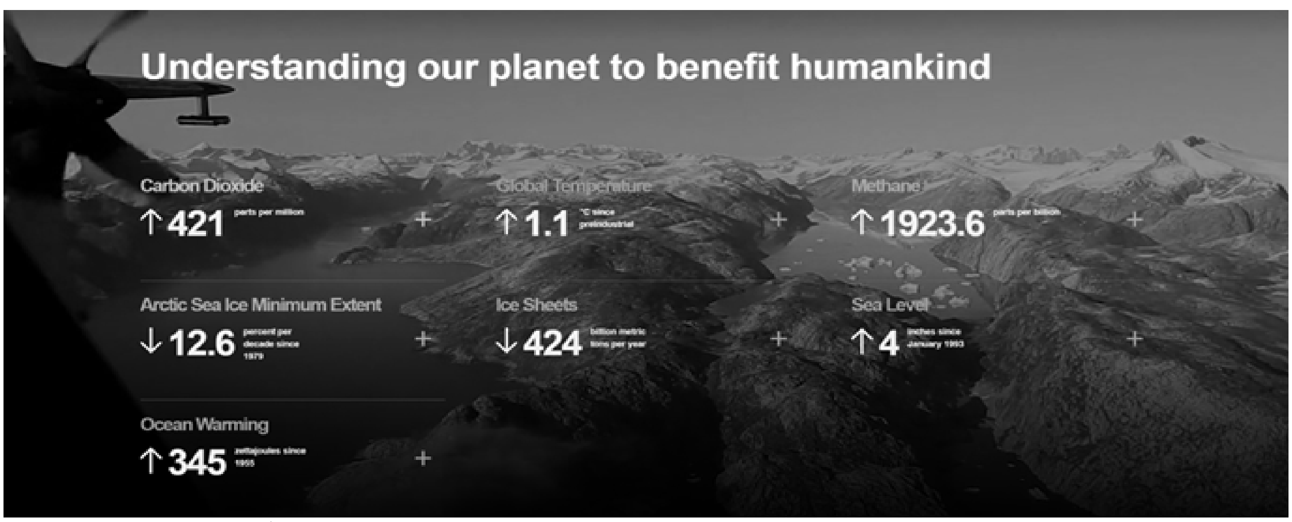


Figure 1-2: Earth climate data (NASA)
Source： https://climate.nasa.gov/

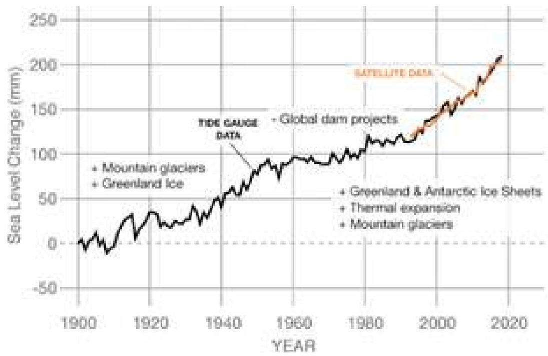


Figure 1-3: Sea level change from 1900 to 2008
Source： https://climate.nasa.gov/vital-signs/sea-level/

In the worst-case scenario, Venice could disappear beneath the sea by as early as 2100.

Climate change has also resulted in ocean warming. Our global oceans cover over 70% of the Earth's surface and possess high heat capacity. Since modern records began in 1955, 90% of global warming has occurred in the oceans, leading to an increase in internal heat content. The heat stored in the oceans causes seawater to expand, contributing to 1/3 to 1/2 of the global sea level rise. Most of the increased energy is stored in the surface layer up to 700 meters deep. The last decade has been the warmest for the oceans in at least a century, with 2022 being

Figure 1-4: The streets of Venice are flooded
Source:https://www.themayor.eu/web/files/articles/9964/main_image/thumb_1024x663_san-marco-venice.jpg

the hottest recorded year and the year with the highest global sea levels. Over recent decades, due to increased greenhouse gases, the oceans have absorbed 90% of the warming, with the top few meters of the ocean holding as much heat as the entire Earth's atmosphere. The ongoing warming of the oceans has far-reaching impacts, including sea level rise due to thermal expansion, coral bleaching, accelerated melting of major ice sheets, intensified hurricanes, and changes in ocean health and chemistry.

As an example, coral reefs, the biodiversity hotspots

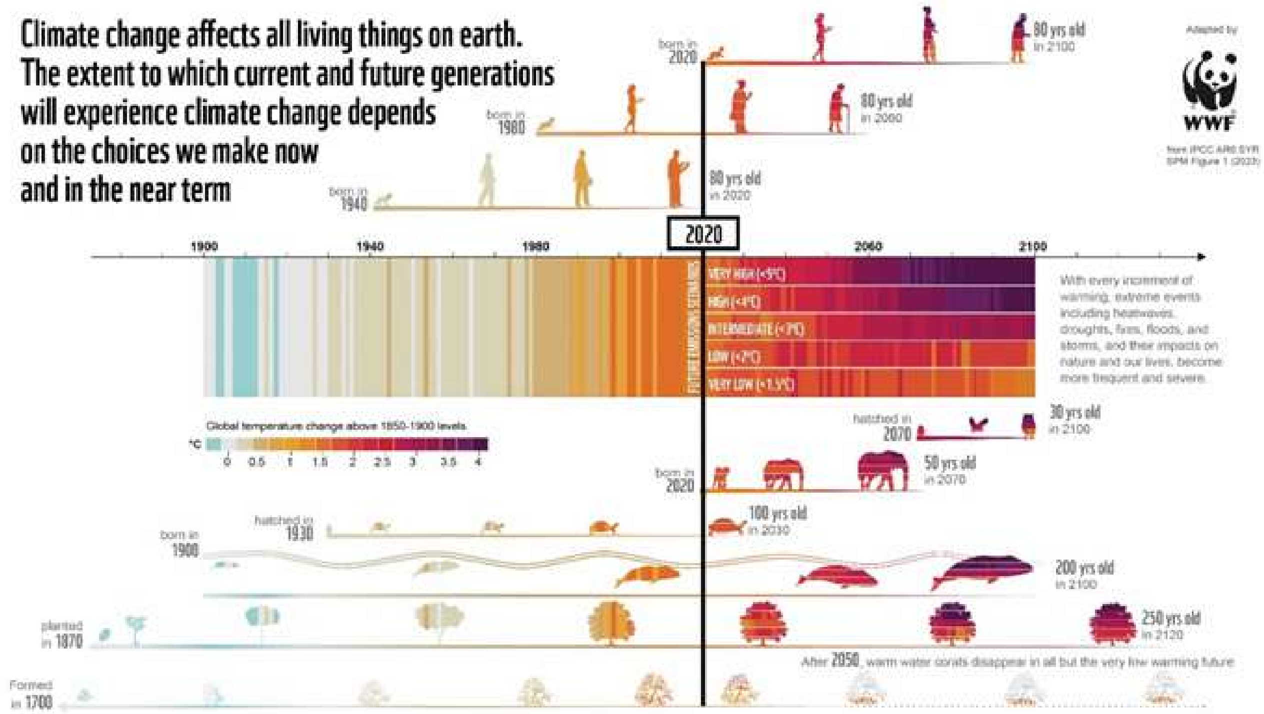
Figure 1-5: High water in Venice
Source: https://ichef.bbci.co.uk/news/976/cpsprodpb/DEAC/production/_109640075_hi057946699.jpg.webp

Figure 1-6: Warming oceans cause coral bleaching

Source:https://ichef.bbci.co.uk/news/976/cpsprodpb/4DE0/production/_95563991_ec96f6d5-6a4e-4018-95d5-839b33120b0d.jpg.webp

Figure 1-7: Historical global temperature and future emissions scenarios and their impact on the entire life cycle of individual species (Source: International Fund for Nature)

Source:https://files.worldwildlife.org/wwfcmsprod/files/Publication/file/160dm65dny_WWF_IPCC_Timeline_CMYK.jpg?_ga=2.221719569.800227509.1701011522-619232512.1701011522



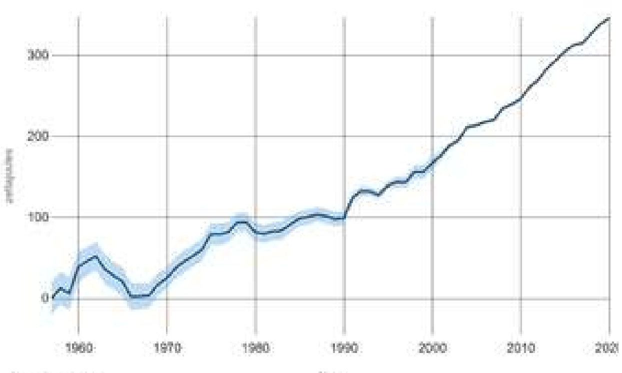


Figure1-8:Changes in ocean heat Content since 1955 (NOAA)

Source:https://climate.nasa.gov/vital-signs/ocean-warming/#:~:text=Covering%20more%20than%2070%25%20of,heat%20as%20Earth's%20entire%20atmosphere.

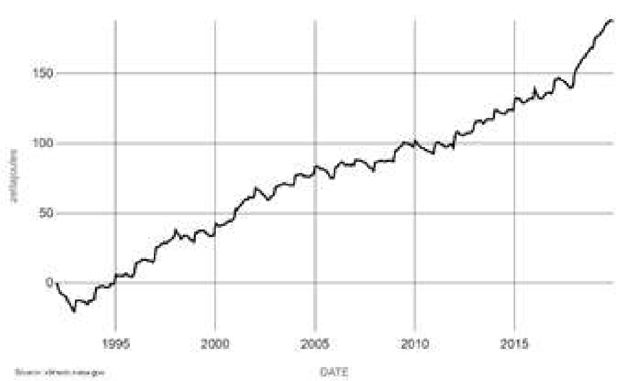


Figure 1-9:Changes in ocean heat Content since 1992 (NASA)

Source:https://climate.nasa.gov/vital-signs/ocean-warming/

often referred to as the "tropical rainforests of the sea," are experiencing rapid degradation due to climate change. The uppermost layer of the ocean (approximately 250 feet) has been warming at an average rate of about 0.11 degrees Celsius per decade since the 1970s. Corals serve as shelters for marine life, and coral reefs are the most diverse ecosystems globally. However, climate change has become a significant factor in coral reef mortality. Mass coral bleaching indicates a rapid deterioration of the marine environment. According to IPCC estimates, a 1.5°C increase in sea temperature would result in the disappearance of 70% of warm-water corals, and with a rise exceeding 2°C, almost all warm-water corals would vanish.

The ocean warming caused by climate change has also led to significant changes in the global coverage of major sea ice. The area covered by global ice caps has significantly decreased with climate warming, averaging a reduction of 424 billion tons annually. Greenland and Antarctica hold about two-thirds of the Earth's freshwater. As the Earth's surface and oceans continue to warm, these ice caps are continuously melting. Antarctica is melting at an average rate of approximately 1500 billion tons per year, while Greenland loses about 2700 billion tons annually. Since 1993, meltwater from these ice caps has contributed to about one-third of the global average sea level rise. Furthermore, the minimum coverage of Arctic sea ice has been shrinking by 12.6% per decade since 1979.

Climate change has a cascade of interconnected impacts on Earth's ecology, humans, and other living organisms. Under the influence of climate change, water resources essential for the survival of humans, animals, and plants are facing severe pollution. Clean water sources for consumption are decreasing due to rising sea levels, storms causing farmland erosion, and saltwater intrusion. Intense precipitation increases the likelihood of agricultural runoff entering oceans, lakes, and streams, further contaminating water sources. Additionally, global soil nutrients are gradually depleting due to climate change. Heavy rainfall can erode soil and deplete


Figure 1-10, 1-11: Arctic ice melt

Source:https://berlingske.bmcdn.dk/media/cache/resolve/image_x_large_vertical_md/image/168/1680973/24440300-.jpg; https://depositphotos.com/cn/photo/leopard-seal-resting-on-ice-floe-103251894.html

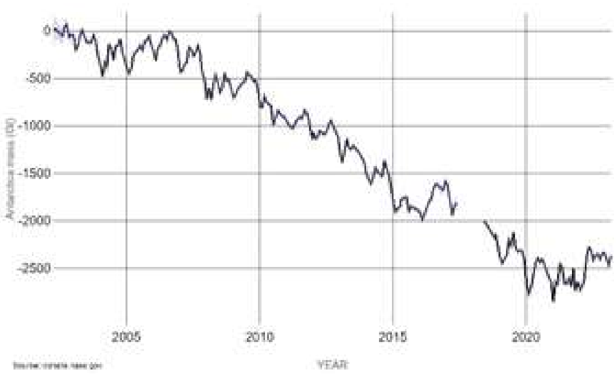


Figure 1-12:Mass change in Antarctica since 2002

Source: https://climate.nasa.gov/vital-signs/ice-sheets/

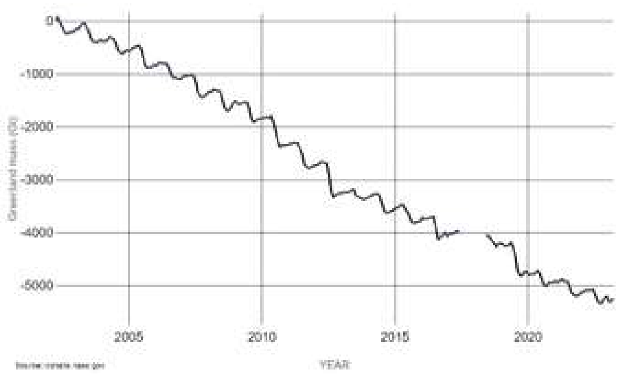


Figure1-13: Mass change in Greenland since 2002

Source: https://climate.nasa.gov/vital-signs/ice-sheets/

its nutrients, thereby damaging crops. On the other hand, populations engaged in agricultural production face various climate-related health risks, such as high temperatures, extreme weather events, increased pesticide exposure due to rising pest populations, disease-carrying pests like mosquitoes and ticks, and deteriorating air quality. Thus, climate change indirectly contributes to a health crisis among agricultural populations.

Furthermore, climate change significantly affects global food security. While higher temperatures may increase crop yields in some regions, the overall impact of climate change on agriculture is expected to be negative. Events like droughts, floods, and extreme weather are projected to reduce food production, leading to a decrease in food supply and a subsequent rise in food prices. Elevated food prices exacerbate hunger, poverty, and inequality, particularly affecting vulnerable populations. For instance, in drought-prone regions like Kenya in Africa, crop failures due to reduced yields have led to the loss of livestock, livelihoods, and sources of food and income for many local cattle herders. Simultaneously, food prices in the region have soared.

Moreover, as climate change intensifies, people's homelands may cease to exist, and resource conflicts may force displacement. Climate change indirectly contributes to regional conflicts, which, in turn, exacerbate the impacts of climate change. With the worsening climate crisis in the coming years and decades, more people will be compelled to leave their homes due to reasons such as desertification and rising sea levels. On February 20, 2017, the world's youngest nation, South Sudan, declared a famine. Prolonged internal conflicts and drought caused nearly five million people (over 40% of the total population) to face food insecurity. The National Director of the World Food Programme, Joyce Luma, stated in 2016 that South Sudan was experiencing a "deadly mix of conflict, economic hardship, and reduced rainfall." Sudan and Darfur have diverse ecological zones, from the arid deserts in the north to the subtropical environment in the south. In the decades leading up to the outbreak of war in 2003, the Sahel region of northern Sudan's Sahara Desert advanced southward by nearly a mile annually, with a 15%-30% decrease in average annual rainfall. These long-term climate trends significantly impacted Sudan's two main agricultural systems, affecting small farmers and pastoralists dependent on rain-fed agriculture. Rapid desertification and drought eroded the natural resources supporting the livelihoods and peaceful coexistence of these two communities, leading to continuous conflicts between the two ethnic groups, causing social upheaval, jeopardizing regional stability, and forcing local populations to leave their homes and become refugees in neighboring countries. Other nations worldwide will face immense pressure in dealing with the influx of refugees and resource allocation issues.

Human activities, accelerated by urbanization and industrial production since the mid-20th century,

Figure 1-14: Unity to fight the pandemic

Source:https://www.flickr.com/photos/worldmeteorologicalorganization/40040249760/in/faves-163849083@N02

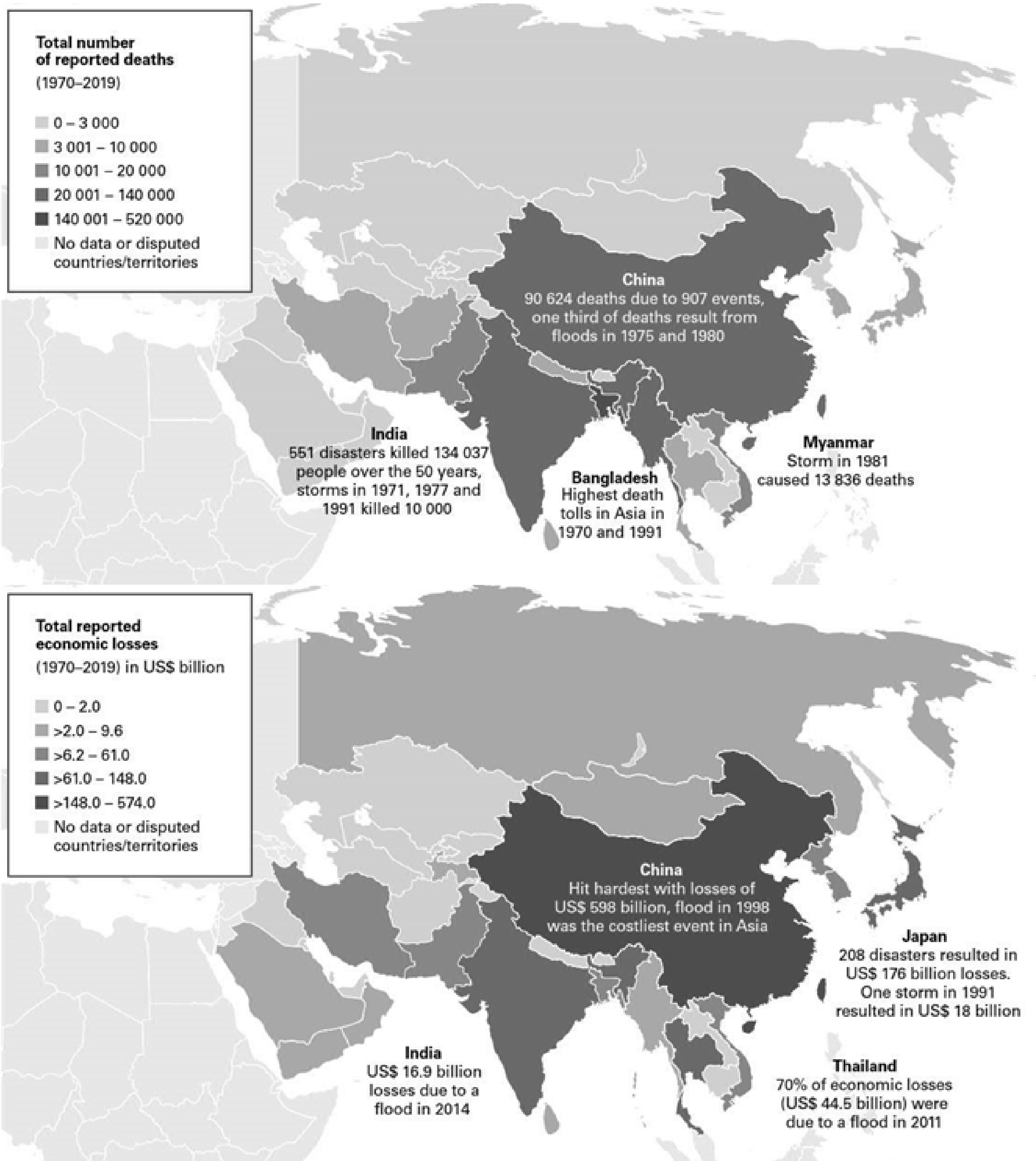


Figure 1-15: Asian disaster damage report

Source: https://www.uncclearn.org/wp-content/uploads/library/1267_Atlas_of_Mortality_en.pdf

have contributed to global population growth and a noticeable increase in carbon emissions. The heat-absorbing nature of carbon dioxide has had a profound impact on the environment, resulting in global climate warming, reduction of global ice caps, and rising sea levels. Global climate warming also intensifies and contributes to an increase in the frequency and extent of natural disasters such as droughts, floods, wildfires, and storms. According to the World Meteorological Organization's "Atlas of Mortality and Economic Losses from Weather, Climate and Water Extremes (1970-2019)," there have been over 11,000 climate-related disasters globally during this period, causing over two million deaths and losses amounting to $36.4 trillion. The deadliest disasters in terms of casualties were droughts

(650,000 deaths), storms (over 577,000 deaths), floods (58,700 deaths), and extreme temperatures (over 55,700 deaths). Hazards related to weather, climate, and water accounted for 50% of all disasters worldwide, 45% of reported deaths, and 74% of reported economic losses. It's noteworthy that over 91% of deaths occurred in developing countries.

In summary, climate change threatens human survival with significant impacts such as rising sea levels, ocean warming, loss of Earth's freshwater reserves, degradation of water and soil resources leading to pest and disease outbreaks, agricultural and food crises, population migration and regional conflicts, and an increase in the frequency and scope of natural disasters. Human activities are responsible for triggering and accelerating global climate change, and as climate change continues to rapidly encroach upon human activities, ecosystem productivity decreases. In the long run, climate change will fundamentally disrupt Earth's ecological balance, destroy vital resources essential for human survival, and ultimately lead to severe consequences such as societal disorder, environmental degradation, and economic decline.

1.1.2 Impact of Climate Change on China

China, as the world's largest developing country and one of the major contributors to carbon emissions, is significantly affected by climate change. Economic activities are concentrated in coastal urban clusters, and China experiences frequent climate-related disasters, resulting in substantial economic losses and casualties. The need for carbon reduction actions in rapidly developing China is both daunting and urgent.

In contrast to African countries facing climate impacts of drought and low rainfall, China frequently encounters the threat of flooding, making it highly susceptible to water-related disasters. Historical records indicate that from 206 BCE to 1949, during the 2155 years leading up to the establishment of the People’s Republic of China, major flooding occurred 1029 times, almost once every two years. Large cities were not immune to the ravages of floods, with historical accounts documenting five instances of floods reaching Beijing and eight instances affecting Tianjin.

In 1931, China experienced a catastrophic flood affecting 16 provinces, with Anhui, Jiangxi, Jiangsu, Hubei, and Hunan suffering the most severe consequences. The flooded area in eight provinces reached 94,466 square kilometers. Statistics show that half of the houses were washed away, nearly half of the population became displaced, and millions were affected, with 3.7 million fatalities. The 1954 major flood covered an area of 160,000 square kilometers, with 113,000 square kilometers seriously affected. The Yangtze River flood submerged over 31,000 square kilometers of farmland, resulting in 33,000 deaths. The relief costs for natural disasters amounted to 3.2 billion yuan. Four years later, in 1958, a massive flood occurred at Zhengzhou's Huayuankou on the Yellow River, leading to the collapse of the Zhengzhou Yellow River Iron Bridge. In 1963, the Haihe River basin experienced an unprecedented flood, affecting an area of 40,966 square kilometers and reducing grain production by over 3 million tons.

According to statistics from the “1970-2019 Asian Disaster Damage Report,” between 1970 and 2019, China reported a total of 907 climate-related disasters, resulting in economic losses totaling $59.8 billion and causing 90,624 deaths. One-third of the deaths were attributed to the extraordinary rainfall and floods in Zhumadian, Henan, in 1975 and the massive rainfall-induced flooding in the Upper Yangtze River Basin in 1981. In 1998, a once-in-a-century flood affected nearly half of China, with the Yangtze, Nenjiang, Songhua, and other major rivers experiencing turbulent floods and rapid water level increases. Approximately 8 million military and civilian personnel fought against the floods, and the Jingguang Railway was blocked for 100 days. This flood, considered the “most expensive disaster event in Asia” to date, resulted in a direct economic loss of $4.702 billion, and the disaster caused a reduction of over a hundred billion kilograms in grain production.

In 2017, Wuhan, China, was impacted by a mid-stream large-scale flood and unusual autumn flooding of the Han River, causing direct economic losses of 93.9 billion yuan in the Yangtze River basin. In 2021, flooding in China affected 58.9 million people, resulting in 590 deaths or missing persons, the emergency relocation of 3.515 million people, the collapse of 203,000 houses, and direct economic losses of 240.6 billion yuan.

On July 29, 2023, under the influence of Typhoon "Dusu Ray," ZHUOZHOU City in Hebei Province experienced continuous heavy rainfall, causing a sharp rise in the water levels of multiple rivers and severe urban flooding in some areas. According to statistics as of 10:00 on August 1, the number of people affected in the entire city of Zhuozhou reached 133,913, with an affected area of 225.38 square kilometers and significant economic losses.

The compounding effects of global warming and urban clustering also contribute to the increasing frequency of extreme high-temperature events in Chinese urban clusters, posing risks to the safe operation of cities. Taking the Yangtze River Delta urban cluster, the world's sixth-largest, as an example: located on the east coast, the Yangtze River Delta is a region with developed economy, concentrated wealth, high population density, and the highest level of urbanization in China. However, this "prosperous area" is often subject to the control of the West Pacific subtropical high-pressure system, making it prone to prolonged periods of high temperatures during the summer. In recent years, extreme high-temperature events in the Yangtze River Delta have become increasingly prominent.

Taking Shanghai, the core city of the Yangtze River Delta urban cluster, as an example, since mete-

Figure 1-16: flood in 1998

Source: https://www.bbc.com/zhongwen/trad/chinese-news-53400445

Figure 1-17: People in Shanghai during extreme heat in 2022
Source:https://global.chinadaily.com.cn/a/202207/22/WS62d9d811a310fd2b29e6db6a.html

orological records began in 1873, Shanghai has experienced a total of 21 days with temperatures exceeding 40°C. In 2022, there were 7 such days, ranking first in history, followed by 5 days in 2013, 3 days in 2017, 2 days in 1934, 2 days in 2016, 1 day in 2009, and 1 day in 2010. Relevant statistics indicate that due to the combined effects of climate change, the urban heat island effect, and regional extreme high-temperature events, the probability of the Yangtze River Delta urban cluster experiencing extreme high temperatures is 60 times higher than in the 1950s, with greater intensity and longer duration.

1.1.3 Necessary Actions on Climate Change

The causes of climate change include natural factors such as variations in solar activity and major volcanic eruptions. However, since the 19th century, human activities have been the primary driver of climate change. The Intergovernmental Panel on Climate Change (IPCC) in its Sixth Assessment Report (AR6) "Climate Change 2023" unequivocally states that the substantial emissions of greenhouse gases resulting from human activities are undeniably responsible for global warming. The report elevates the language from previous expressions like "likely," "very likely," "extremely likely" to "established fact" and "undeniable" regarding the role of human activities in global warming. Unsustainable energy use, land use and its changes, lifestyle, and consumption and production patterns in human activities contribute to the continued increase in global greenhouse gas emissions.

The primary greenhouse gases causing climate change are carbon dioxide and methane. According to United Nations data, the use of fossil fuels—coal, oil, and natural gas—is the predominant cause of greenhouse gas emissions, accounting for over 75%

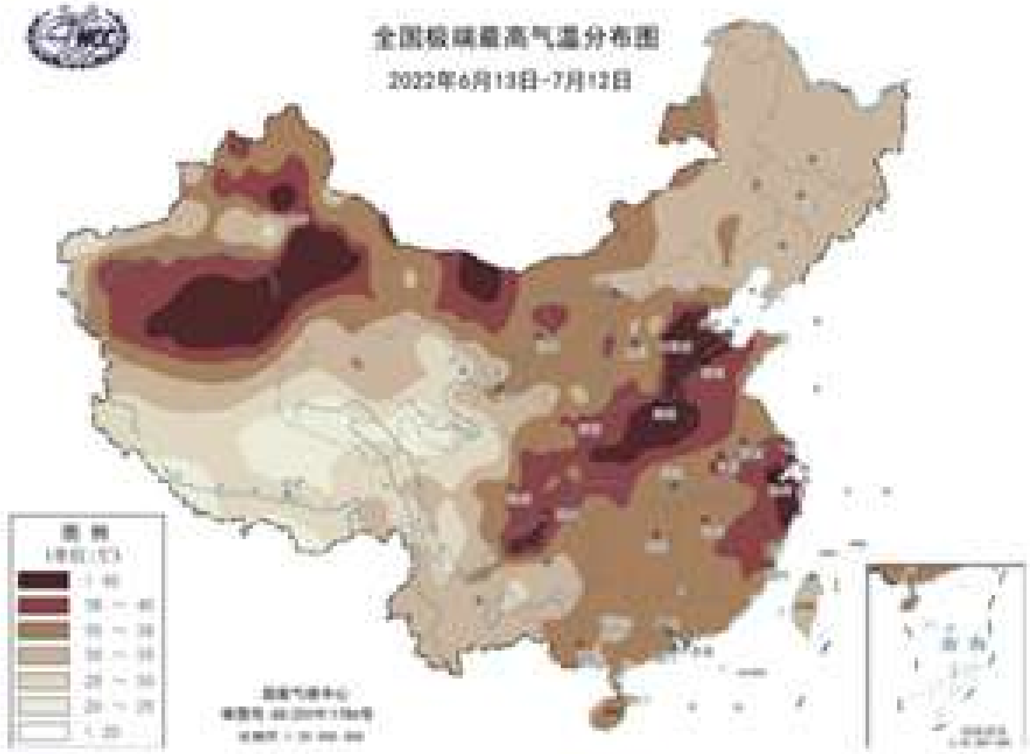
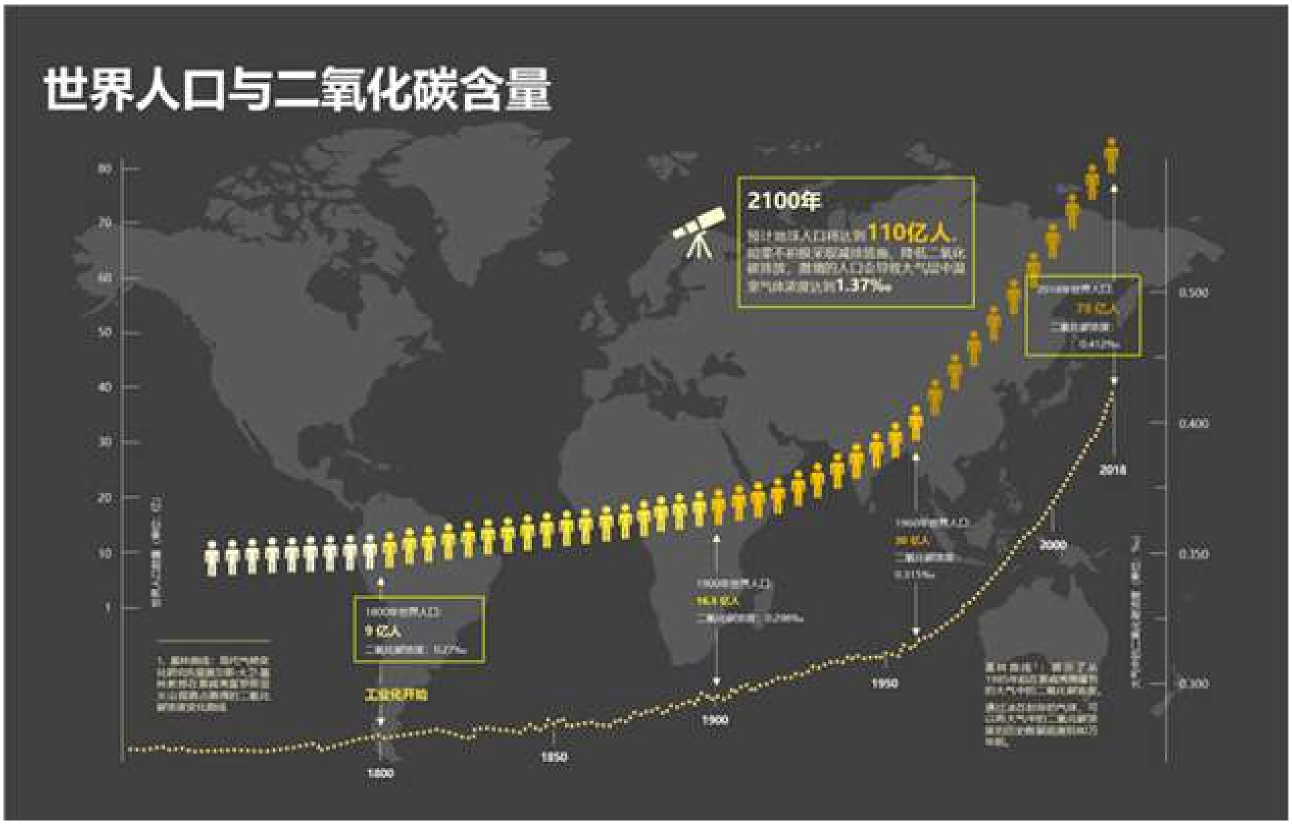


Figure 1-18: National extreme maximum temperature distribution map from June to July 2022

Source:http://cmdp.ncc-cma.net/extreme/hightemp.php?product=hightemp_moni

of global greenhouse gas emissions and nearly 90% of all carbon dioxide emissions. Sectors such as electricity generation, manufacturing, transportation, food production, and building energy supply involve the use of fossil fuels. Human activities generate greenhouse gas emissions, causing the world to warm at a faster rate than any period in the past two thousand years. In the past 100 years, the Earth's temperature has risen by 1.1 degrees, accelerating the threat to human survival. Global collaboration for a comprehensive net-zero carbon transition is urgently imperative.



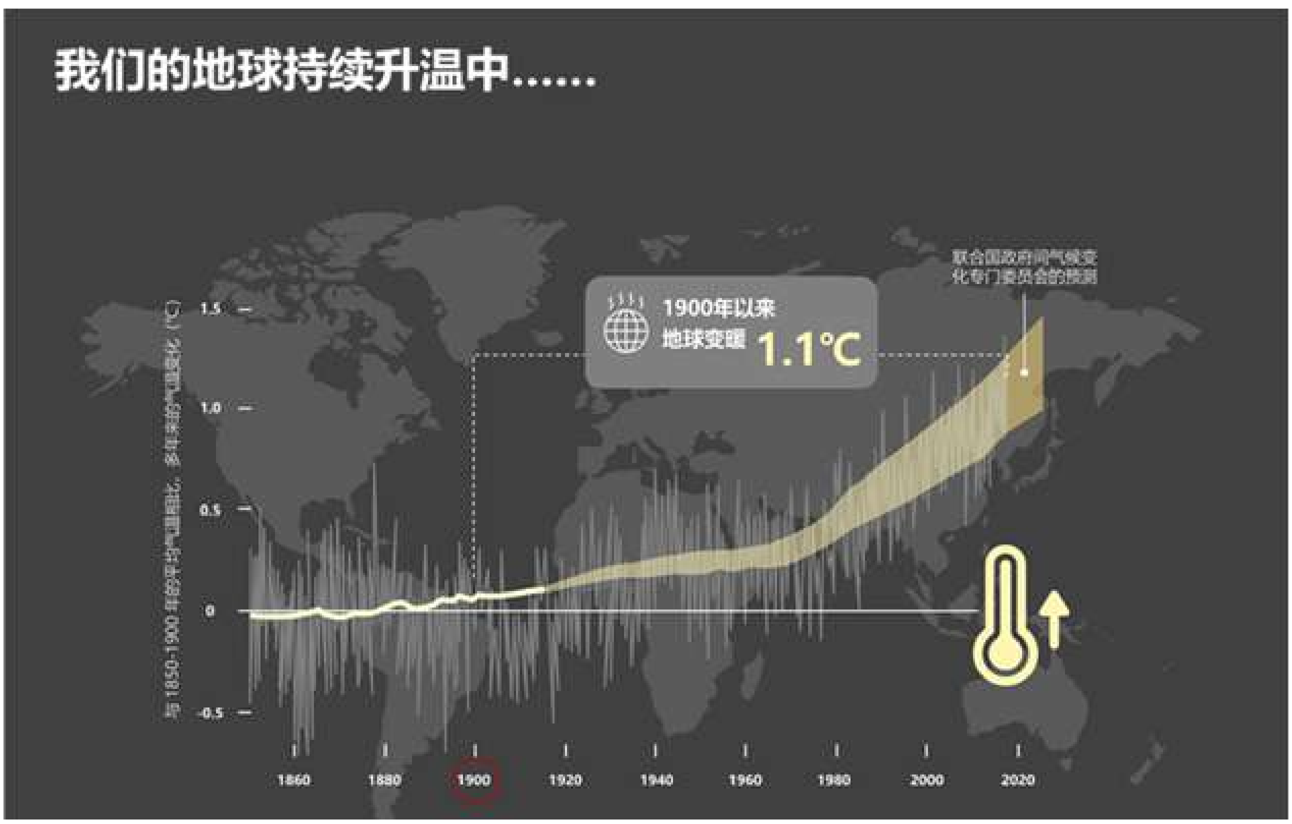


Figure 1-19: Human activities result in global warming Source: draw by author

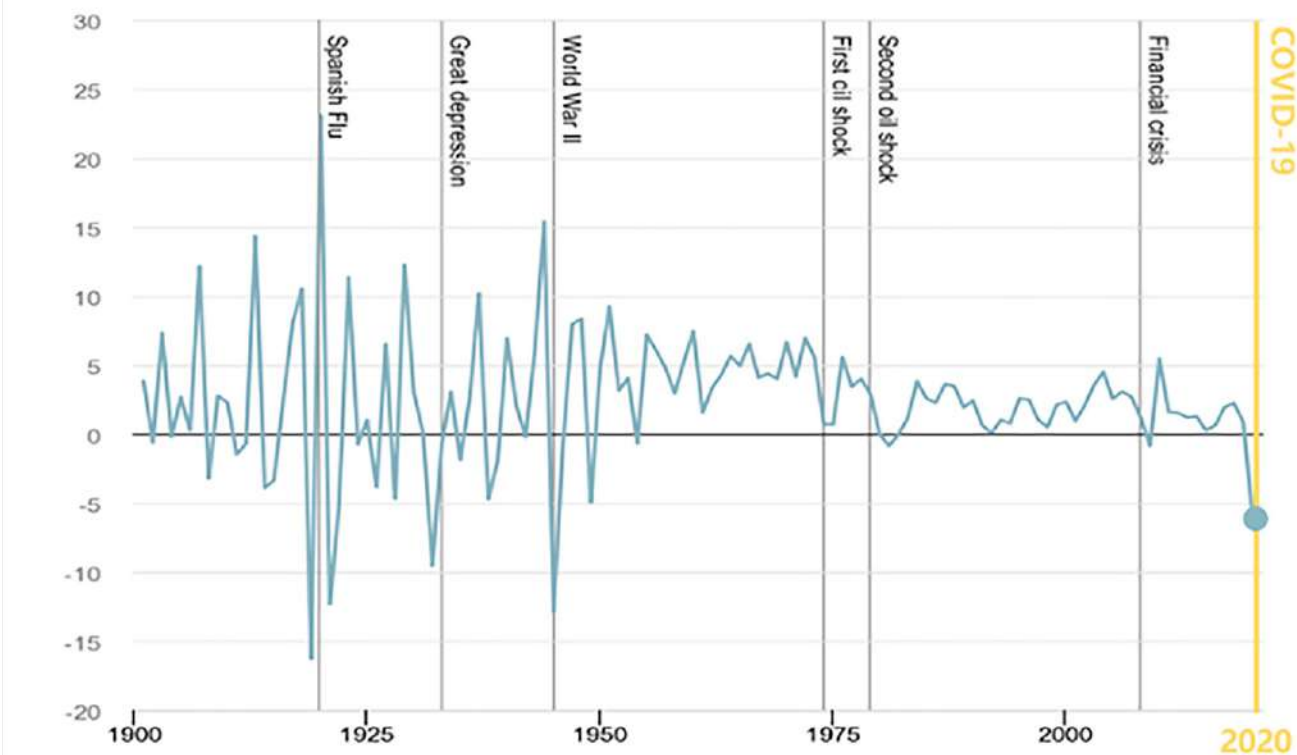


Figure 1-20: Annual Change Rate of global Energy Demand (1900-2020)

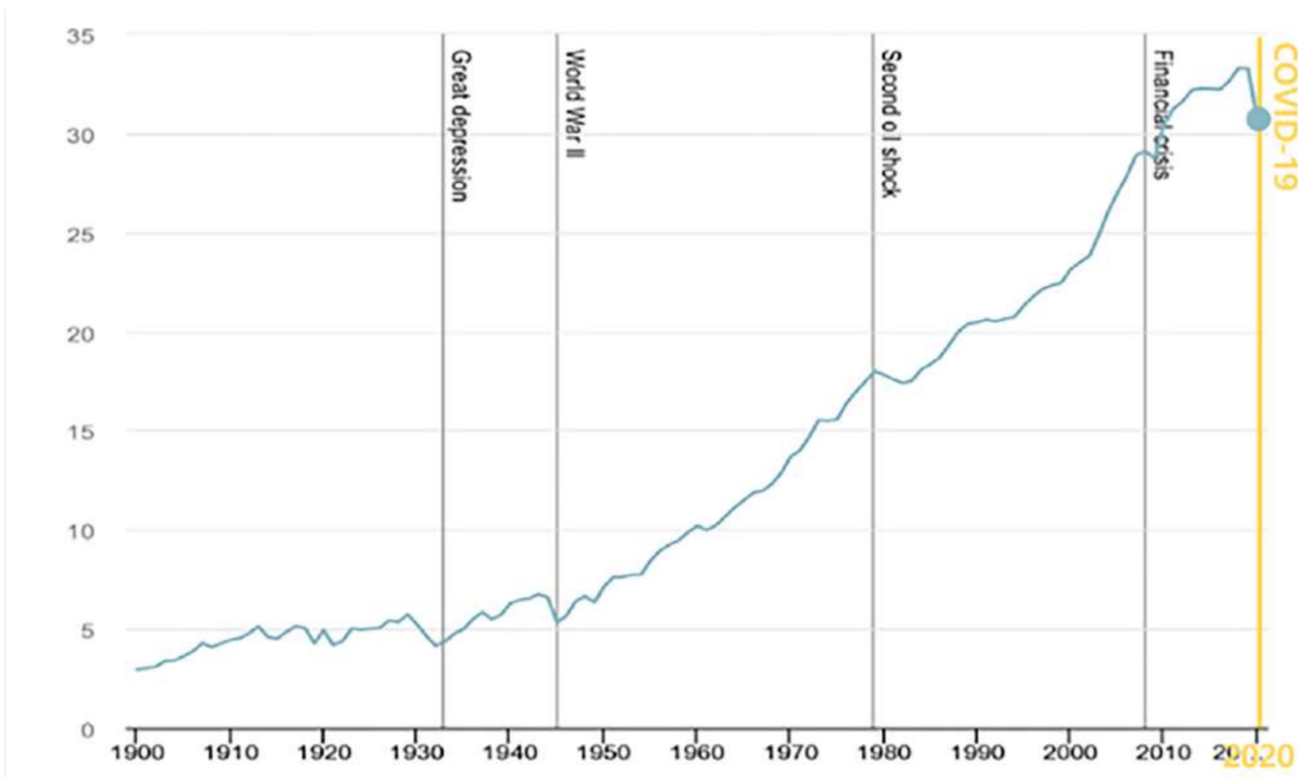


Figure 1-21:Global energy-related CO_2 emissions (1900-2020)

Source: https://www.iea.org/reports/global-energy-review-2020/global-energy-and-co$_2$-emissions-in-2020

1.2 Importance of Urban Net-Zero Carbon Transition

The undeniable contribution of greenhouse gas emissions from human activities to global climate change has underscored the critical importance of urban areas, which house over 50% of the global population, in achieving net-zero carbon emission goals. Cities contribute 80% of the global GDP while accounting for 70% of energy consumption and greenhouse gas emissions. Furthermore, these figures are on a continual upward trajectory, with urban populations expected to double by 2050. Thus, cities not only represent hotspots for the impacts and risks of climate change but are also integral components of solutions to address climate change.

The climate reports of the United Nations' Intergovernmental Panel on Climate Change (IPCC) have started to dedicate separate sections to urban, residential, and infrastructure measures for mitigating climate change. These reports emphasize the pivotal role of cities in climate change mitigation, asserting that urban systems are crucial for achieving significant emission reductions and advancing climate-resilient development, especially in the context of comprehensive planning that encompasses material, natural, and social infrastructure.

According to statistics from the International Energy Agency (IEA), the top four sources contributing to global energy-related carbon emissions are energy production and heating (40%), industrial production (23%), transportation (23%), and the construction sector (10%). Importantly, these key sectors are closely intertwined with urban areas, emphasizing the interconnectedness of cities with critical domains affecting global carbon emissions.

Tailored and highly efficient urban mitigation solutions and strategies can also support broader sustainable development goals. The key focus for urban carbon reduction can be summarized through three major strategies:

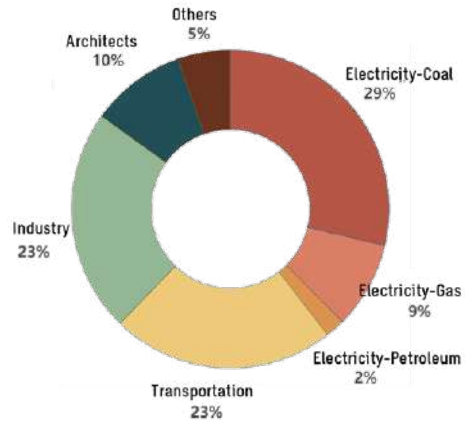


Figure 1-22: Composition of global energy-related CO_2 emissions

Source: https://www.iea.org/data-and-statistics/charts/global-energy-related-co$_2$-emissions-by-sector

a. Reducing Urban Energy Consumption through Spatial Planning and Construction. This includes the implementation of comprehensive and inclusive land-use planning and decision-making. Achieving a compact urban form involves regional efforts to improve the balance between residential and work areas. Methods to curtail carbon emissions related to transportation include strengthening public transportation systems, promoting green commuting, and advocating for remote work through digitization. Additionally, emphasis on the efficient design, construction, renovation, and use of buildings is paramount.

b. Adjusting the structure of energy production and heating, emphasizing clean energy sources. This encompasses adjusting the structure of energy generation and heating, upgrading and transforming high-energy-consumption industries, establishing a low-carbon industrial system, and fostering green and circular economies. The widespread promotion of new energy vehicles in urban transportation is also pivotal.

c. Strengthening carbon absorption and storage in the urban environment through the development and investment in the urban ecological network. This involves substantial investment and construction in urban ecological networks, integrating blue-green infrastructure with traditional grey infrastructure. Such an approach not only reduces the risks of extreme events like heatwaves, floods, heavy rainfall, and droughts but also generates mutual benefits for health, well-being, and livelihoods.

To establish and achieve emission reduction targets in urban areas, a multi-level governance and participation approach is essential. Additionally, city governments must collaborate with international organizations, national governments, and local stakeholders to mobilize global climate action resources for a range of low-carbon infrastructure projects and integrated urban land-use and spatial planning schemes across critical sectors.

1.2.1 Goals and Pathways for Urban Climate Change Resilience

Effectively managing the primary sources of carbon emissions in cities is crucial and urgent for addressing climate change. Research indicates that per capita energy consumption in urban areas is typically about three times that in rural areas, leading to significant energy demand and substantial atmospheric emissions.

In this context, understanding and efficiently managing carbon emission activities within cities are paramount.

a. Establishing Carbon Reduction Goals: Cities must set clear carbon reduction targets, prioritizing them based on scientific evidence, considering specific urban conditions and resource availability to ensure feasibility and sustainability. To achieve these goals, cities should leverage their strengths in resource, technology, and human capital aggregation. This implies proactive investments in areas such as energy efficiency, renewable energy development, and sustainable transportation systems to yield greater returns in reducing carbon emissions and improving urban living quality.

b. Building a Global Urban Collaboration Platform: Facilitating collaboration among cities globally fosters the sharing of technology and experiences. Cross-city collaboration accelerates the dissemination of carbon reduction technologies and strategies, enhancing the global synergy in climate action. Simultaneously, establishing a green humanistic value system is crucial in shaping environmental awareness and sustainable lifestyles among urban residents, further reducing carbon emissions.

c. Clear Action Paths and Systemic Measures: Urban carbon reduction initiatives require well-defined action paths and systematic measures. This involves enhancing urban infrastructure, promoting clean energy, implementing carbon pricing policies, encouraging green transportation, and urban greening efforts. Cities should aim for achieving net-zero carbon emissions, necessitating the use of carbon offsetting and carbon neutrality measures in situations where carbon emissions cannot be completely eliminated.

In summary, by understanding and effectively managing urban carbon emissions, setting clear carbon reduction goals and priorities, leveraging urban resources and strengths, establishing a global urban collaboration platform and a green humanistic value system, and systematically implementing net-zero carbon transition measures, cities can play a pivotal role in rapidly mitigating or halting climate change, creating a more sustainable and livable future for humanity. This is a challenging yet crucial task that requires joint efforts from governments, businesses, and residents for successful implementation.

1.2.2 Global Cities' Actions on Climate Change

In the face of climate change and increasing climate-related disasters, cities worldwide have proactively adopted measures to address these challenges. An escalating number of countries, cities, businesses, and other entities are committing to achieving net-zero emissions. Over 70 countries, including major polluters such as China, the United States, and the European Union, have set net-zero emission targets, accounting for approximately 76% of global emissions. Over 3000 companies and financial institutions are collaborating with the Science-Based Targets Initiative to reduce emissions based on climate science. More than 1000 cities, 1000 educational institutions, and 400 financial entities have joined the Race to Zero, pledging rigorous actions to halve global emissions by 2030. In this article, we will explore four cities actively engaged in climate action: Copenhagen in Denmark, the "Solar City" initiative in the Netherlands, Totnes in the United Kingdom, and San Francisco in the United States.

1.2.2.1 The City of Green Cycling - Copenhagen, Denmark: Sustainable Lifestyle

Copenhagen, renowned as the "City of Environmental Protection," stands out for its outstanding environmental initiatives. The city's bicycle culture is deeply ingrained, with nearly half of its residents using bicycles as their daily commuting mode. This cycling fervor originated in the 1970s when the Danish Cyclists' Federation proposed a bicycle network plan in response to the oil crisis, garnering government support.

Since 1997, the Copenhagen government has implemented a series of regulations to curb car growth and promote the use of bicycles and public transportation. In 2000, the government introduced the "Copenhagen Traffic Safety Plan," aiming to reduce the bicycle accident mortality rate by 40% from 2001 to 2012, creating a safer cycling environment. The "Bicycle Policy 2002-2012" was released in 2002, focusing on the construction of bicycle greenways and improvements to parking facilities to further enhance the cycling environment and encourage green commuting. In 2007, the government formulated the "Ecological City" plan, envisioning Copenhagen as the "World's Best Bicycle City" and targeting a minimum 50% bicycle commuting rate.

The government not only enacts policies but also heavily invests in bicycle infrastructure. Transformations include widening bicycle lanes, constructing bicycle bridges, and implementing a 300-mile bicycle highway. Copenhagen now boasts a comprehensive network of bicycle lanes, distinguished by elevation and color markings, separated from motor vehicle lanes. Bicycle lanes are categorized for left turns, right turns, and straight paths, with bidirectional lanes on one-way streets. The bicycle highway encourages long-distance cycling and provides inflation and repair stations.

Furthermore, the Copenhagen government has introduced digital technology, investing 60 million Danish crowns to establish 380 "smart traffic signals" that dynamically adjust signals in real-time to enhance traffic efficiency. The "green wave" signals on bicycle lanes recommend a speed of 20 km/h, with cyclists adjusting their speed based on the intensity of the green light to improve passage rates. In 2016, Copenhagen boasted 265,700 more bicycles than cars. Simultaneously, the government has undertaken efforts to elevate the city's cycling image. They have established a public website offering practical information and feedback mechanisms. Annual events such as Bicycle Day, Car-Free Day, and "Bike to Work" are organized to enhance the image of cycling and strengthen citizens' environmental awareness.

In summary, the Copenhagen government advocates for a green lifestyle, formulating a sustainable development plan that includes 50 projects related to green renewable resources and green buildings. Their commitment is evident in their endeavor to transform Copenhagen into the world's first zero-emission city by 2025.

1.2.2.2 Zero Carbon Emissions - Heerhugowaard, the Netherlands: Efficient Urban Planning

The Netherlands has consistently maintained a leading position in the field of green emissions reduction. Heerhugowaard, a suburban satellite city located approximately 30 kilometers north of the capital city Amsterdam, serves as an exemplary model for sustainable new urban development projects. It fully embraces sustainable development principles and technologies, including compact mixed-use development, green transportation, eco-passive architectural design, diverse clean energy sources, as well as a proprietary water storage and protection system, to ultimately achieve its goal of zero carbon emissions.

Residential areas in Heerhugowaard embody the concept of a "compact city," surrounded by expansive water bodies and green spaces, creating a pleasant living environment where essential facil-


Figure 1-23: Copenhagen Bicycle Festival

Source: https://images.ctfassets.net/761l7gh5x5an/2CYcFX3CBqelhPBpmzzdFa/2f08c8a05d22b9fc5b4e43e857da1f7f/162880_orig.jpg?fit=thumb&fl=progressive&w=1200&h=1200

ities such as shops, schools, daycare centers, and hospitals are within walking distance. The city's roadways and sidewalks are designed separately, with certain residential areas inaccessible by direct car routes, encouraging green modes of transportation like walking and cycling.

Adopting eco-passive energy-saving design strategies, 80% of Heerhugowaard's buildings face north and south, equipped with solar panels. The total area covered by photovoltaic panels exceeds 50,000 square meters, making it one of the world's largest photovoltaic communities, often referred to as the "Solar City" of the Netherlands. The city is also home to three windmills, achieving energy independence and a negative carbon emissions status. Additionally, the city actively employs renewable energy sources such as geothermal and biomass, while implementing energy-saving technologies like heat storage and high insulation.

Heerhugowaard features a unique water storage and protection system known as the "circular open water," separating residential areas from recreational zones and providing extensive public open spaces. This system primarily utilizes rooftop rainwater collection and purification systems, elevating pond water quality to swimming pool standards, simultaneously serving as rainwater buffers and recreational spaces.

Finally, Heerhugowaard's urban planning emphasizes diversity, incorporating various residential types and distinctive neighborhoods to accommodate different societal groups and age demographics. This approach aims to foster sustainable urban development, breaking away from monotony in city construction.

Figure 1-24: Heerhugowaard aerial view

Source:https://milanium.eu/wp-content/uploads/2022/01/header-270_1920x960-1024x512.jpg

1.2.2.3 Zero Waste - San Francisco, US: Comprehensive Regulatory Policies

In the 1960s, amidst the rise of the environmental movement in the United States, cities in the San Francisco Bay Area initiated waste sorting and management efforts. Through persistent governmental efforts, this work evolved into mandatory regulations in the new century. By 2000, San Francisco had successfully achieved the state-mandated goal of a 50% landfill diversion rate, with a subsequent target to reduce it to 25% by 2010. In 2003, the city set an even more ambitious goal of achieving zero waste by 2020.

The core philosophy behind this goal involves following a hierarchy and principles of waste management, including waste prevention, reduction, promoting recycling, and biological treatment (mainly composting), ultimately aiming to eliminate waste from being landfilled or incinerated. San Francisco, with its outstanding waste management achievements, was recognized as North America's most environmentally friendly city by The Economist's think tank in 2011. In 2012, while the national average landfill rate in the United States stood at 66%, San Francisco reduced it to an impressive 20%, well below the national average.

Behind this remarkable achievement lie three key efforts:

a. Waste Reduction Regulations: San Francisco has implemented various laws and regulations, including bans on certain items and mandatory requirements for the use of recycled materials in construction. These regulations control waste generation at its source, achieving waste reduction.

b. Collaboration between Government and Private Enterprise: The long-term partnership between the San Francisco city government and Recology, a waste management company, enables the government to oversee and promote the construction and

Figure 1-25: San Francisco Street

Source: https://www.dwt.com/files/Uploads/Images/News/06.16_SanjayNangia_SFTrees.jpg

operation of waste sorting facilities. This collaboration ensures that citizens receive support and information on waste sorting. Recology actively engages in social responsibility activities, such as hiring local workers and providing better benefits, bringing social benefits to the community.

c. Effective Incentive Mechanisms for Waste Sorting: San Francisco's city government encourages citizen participation in waste sorting through incentive systems, community engagement, educational campaigns, and continuous improvement of incentive mechanisms. These efforts encourage active participation in waste sorting, fostering a culture of recycling and composting and achieving waste reduction goals.

In summary, cities in the San Francisco Bay Area, especially San Francisco itself, have achieved revolutionary improvements in waste management through a combination of regulations, collaborations, and incentive policies. They serve as an exemplary model in the field of environmental protection, providing valuable insights for other cities to adopt similar measures and promote sustainable waste management and environmental development.

1.2.2.4 Pioneer of Transition – Totnes, UK: Indispensable Social Engagement

Situated in the southwest of the United Kingdom, Totnes gained global recognition as the first city committed to achieving a climate-friendly urban environment and an economic transition toward climate resilience. It has also become a renowned tourist destination in the UK due to its urban transition movement.

Historically rich in tin mining resources, Totnes faced pollution and resource depletion of the Dart River due to over-exploitation. In 1719, the city declared bankruptcy, forced to incur debt to sustain basic operations.

In 2005, Dr. Rob Hopkins, a British scholar, proposed an urban transition concept initially as a response to climate change and oil scarcity. This idea gradually evolved into a series of actions to address contemporary development issues. Dr. Hopkins applied this concept to his hometown Totnes and collaborated with local residents to explore sustainable urban development. Under his advocacy, the Totnes community formed the Transition Town Totnes (TTT) organization, a non-profit operated and led by the local community. Its goal is to aid economic development, reduce environmental impact, and enable the town to better adapt to climate change in the future. Local residents collectively formulated a 20-year Energy Descent Action Plan to reduce dependence on fossil fuels.

The core themes of town transition include "Local Food," "New Energy," and "Community Economy," attempting to establish a sustainable community lifestyle through various local solutions.

a. Local Food: The local food movement emphasizes the importance of rural areas, land, and food, encouraging community members to participate in communal farming and share food. Organic and diverse cultivation methods not only reduce carbon emissions but also enhance food quality. The local food movement has successfully helped the community establish a more resilient food system, promoting low-carbon grain cultivation methods based on ecological agricultural principles.

b. New Energy: Through joint efforts of the government and residents, households in Totnes are equipped with their energy systems, including wind and photovoltaic power. The installation of batteries enables a lifestyle with zero emissions, consumption, and electricity costs. These renewable energy systems are integrated into ancient buildings, becoming part of the city's landscape.

c. Community Economy: Totnes introduced the UK's first "Transition Currency" - the Totnes Pound, encouraging local consumption and reinvesting earned money into local goods and services, creating a

Figure 1-26: Town view of Toniste

Source:https://www.nationalgeographic.com/travel/article/totnes-south-devon-quirkiest-corner-uk-guide virtuous cycle. Local residents jointly resist modern commercial impacts, promoting local economic development, and maintaining the unique economic and cultural characteristics of the locality.

Totnes' town transition is a consensus forged by residents "from the bottom up," revitalized with multifaceted participation and support. It is an effective practice seeking sustainable urban development against the backdrop of the reality of the oil crisis and global climate change. Over 100 towns globally have joined the Transition Town movement, establishing the Transition Network organization.

1.2.3 Chinese Cities' Action On Climate Change

As the world's largest developing country, China is actively taking measures to mitigate carbon emissions during its economic growth. The implementation paths need to be more specific and efficient across policies, finances, industries, and technology. In 2020, the Chinese government introduced the "Dual Carbon" goals, aiming to peak carbon emissions by 2030 and achieve carbon neutrality by 2060.

To attain the "Dual Carbon" objectives, Chinese cities are engaging in multidimensional climate actions:

a. New Deployment for Climate Change Response: Improve the top-level design for climate change response, formulate mid-to-long-term greenhouse gas emission control strategies, and implement national strategies for adapting to climate change.

b. Mitigating Climate Change: Adjust industrial structures, optimize energy structures, promote energy efficiency, control non-CO_2 greenhouse gas emissions, enhance the carbon sink capacity of ecosystems, advance collaborative pollution reduction and carbon reduction efforts, and deepen pilot.

c. Proactive Adaptation to Climate Change: Strengthen climate change monitoring, early warning, and risk management. Enhance the adaptive capacity of natural ecosystems and economic and social systems. Improve climate resilience in key vulnerable regions.

d. Policy System and Support Assurance: Promote legislation and standard development, improve economic policies, actively and steadily advance the construction of a national carbon market, accelerate the establishment of the greenhouse gas statistical accounting and monitoring system, reinforce technological innovation support, strengthen talent training, and enhance capacity building. Conduct nationwide initiatives for green and low-carbon actions.

e. Global Governance in Climate Change Participation: Deepen high-level exchanges for climate change response, advance multilateral and bilateral climate change negotiations, strengthen practical cooperation in responding to climate change.

Since proposing the "Dual Carbon" goals in 2020, China's efforts to achieve these goals have shown initial success, primarily manifested in the following aspects:

a. Establishing a Comprehensive Policy Framework for Carbon Peaking and Neutrality

- The Central Committee of the Communist Party of China incorporated carbon peaking and neutrality goals into plans for ecological civilization construction and overall economic and social development.

- The Central Committee and the State Council issued the "Opinions on Fully Implementing the New Development Concept to Accomplish Carbon Peaking and Neutrality," and the State Council released the "Action Plan for Carbon Peaking Before 2030." Relevant departments formulated 12 implementation plans for key areas and industries, along with 11 support and guarantee plans. All provinces and regions developed local carbon peaking implementation plans, forming a comprehensive "Dual Carbon" policy system that is consistently implemented.

b. Promoting the Green and Low-carbon Transition

of Energy

- Emphasis has been placed on the clean and efficient utilization of coal, achieving over 520 million kilowatts through cumulative energy-saving and carbon reduction transitions of coal-fired units.

- Renewable and clean energy development has been prioritized, with the national renewable energy installed capacity exceeding 1.3 billion kilowatts, surpassing coal-fired capacity for the first time in history.

- Efforts have been made to establish a diversified energy supply guarantee system, including coal, oil, gas, nuclear energy, and renewable energy, further consolidating the foundation of energy security.

c. Continuously Optimizing and Upgrading Industrial Structure

- Supply-side structural reforms have been deepened, with controlled steel production and a reduction of over 40 million tons since the 14th Five-Year Plan.

- Strategic emerging industries such as solar cells, lithium batteries, and electric passenger vehicles have been vigorously developed, becoming new engines for foreign trade. In the first half of this year, exports of these “new three” products grew by 61.6%, driving an overall export growth of 1.8 percentage points.

- Benchmarks for energy efficiency in key industries and energy-consuming equipment have been issued, promoting the upgrading of energy-saving and carbon reduction.

d. Achieving Green and Low-carbon Development in Key Areas

- Significant efforts have been made in developing green buildings, with green building coverage in new construction reaching 91.2% in 2022. Simultaneously, existing buildings are being renovated to achieve a proportion of energy-saving buildings exceeding 65%.

- The adjustment of the transportation structure has been accelerated, with a 4.4% increase in national railway freight volume and a 3.8% increase in waterway freight volume in 2022.

- In the first half of the year, production and sales of new energy vehicles reached 3.788 million and 3.747 million units, respectively, with year-on-year growth rates exceeding 40% each, and the total number exceeded 16.2 million, accounting for over half of the global total.

e. Steadily Improving the Carbon Sequestration Capacity of Ecosystems

- The strategic layout of major functional zones has been optimized, and the delineation of ecological protection redlines has been completed.

- Efforts have been actively made to protect and restore ecosystems in key areas, with a focus on addressing ecological environmental issues in the Yangtze River Economic Belt and the Yellow River Basin. At the same time, efforts are actively promoted in the ecological environmental protection work of the Beijing-Tianjin-Hebei region, the Yangtze River Delta, and the Guangdong-Hong Kong-Macao Greater Bay Area.

- Large-scale national land greening actions have been scientifically carried out, with over 100 million mu of land greening completed annually since the 14th Five-Year Plan.

- China’s forest coverage rate has reached 24.02%, making it one of the countries with the largest and fastest-growing forest resources globally.

f. Improving the Policy System for Green and Low-carbon Development

- Adhering to the principle of prioritizing conservation, controls on total energy consumption and energy intensity have been improved, achieving dual

Figure 1-27The State Council has issued a white paper on China's Policies and Actions to address Climate Change

Source:https://k.sinaimg.cn/n/spider20211027/291/w1080h811/20211027/14b1-b39ef40948cd14e210bc1ca14234749c.jpg/w700d1q75cms.jpg?by=cms_fixed_width

Figure 1-28: The National Development and Reform Commission released the important results of the third anniversary of the major declaration of carbon neutrality

Source:https://www.ndrc.gov.cn/fzggw/wld/zcx/lddt/202308/W020230817519761455850_r75.jpg

control capabilities for carbon emissions and energy consumption.

- Continuous optimization of fiscal resource allocation has been implemented, with tax and fee preferential policies supporting green and low-carbon development. Since 2020, the central government has allocated a cumulative total of 1.78 trillion yuan for ecological environmental protection.

- The issuance of tools supporting carbon reduction and special re-lending supporting the clean and efficient use of coal have been launched. As of June 2023, the balances of these two tools are 453 billion yuan and 245.9 billion yuan, respectively.

- The establishment of the National Green Development Fund, with the initial fundraising reaching 88.5 billion yuan.

- Deepening energy price reforms, promoting the market-oriented reform of on-grid electricity prices for coal-fired power generation, implementing new energy parity on-grid policies, and improving time-of-use electricity pricing mechanisms, completing the dual-price policy for pumped storage power.

g. The Basic Capabilities for “Dual Carbon” Work Have Significantly Improved

- A unified and standardized carbon emission statistical accounting system has been established, incorporating carbon emission statistical accounting into the national statistical survey system.

- The Carbon Peaking and Neutrality Standardization Overall Group has been established, implementing the action to improve 100 energy-saving and carbon reduction standards during the 14th Five-Year Plan.

- Green and low-carbon technological innovation has been strengthened, with the establishment of five national key laboratories in the “Dual Carbon” areas and the promotion of key research and development projects such as “renewable energy technology.” Concurrently, efforts have been intensified in the training of professional talents related to “Dual Carbon.”

h. Actively Participating in Global Climate Governance

- Adhering to the concept of a community with a shared future for humanity, coordinating foreign cooperation and domestic struggles, and facilitating the achievement of the “Sharm El Sheikh Implementation Plan” during the Conference of the Parties to the United Nations Framework Convention on Climate Change. Endeavors have been made to build a fair, equitable, and win-win global environmental governance system.

- Actively promoting the construction of the Green Silk Road, deepening South-South cooperation in response to climate change, actively supporting developing countries in green and low-carbon energy development, and enhancing their capacity to cope with climate change.

1.2.4 The Challenge of Urban Net-zero Carbon Transition

In the effective realization of global carbon emission control goals, it is crucial to recognize that collaborative, timely, and technological breakthroughs are essential measures. However, they come with significant challenges. Currently, progress toward achieving carbon neutrality globally is slow, mainly due to the following reasons, which require thorough consideration and resolution:

a. Lack of Effective Data Sharing and Assessment for Climate Change: Accurate data is essential for monitoring and assessing the impacts of climate change to effectively reduce carbon emissions. However, many regions still face issues of insufficient data, making it more difficult to formulate and implement decarbonization strategies.

b. Lack of Cross-Sectoral Collaborative Models or Technological Pathways: Decarbonization actions require cooperation across various sectors, including government, industry, agriculture, and energy. However, there is currently a lack of effective collaborative models and cross-technological implementation pathways, making collaboration costly and complex.

c. Differences in Environmental Cultural Identity: Different regions and communities have varying levels of awareness regarding the importance and urgency of climate change. This difference results in inconsistencies in decarbonization actions, necessitating broader education and awareness campaigns to raise people's understanding of climate change.

d. Per capita Carbon Emissions are Primarily Concentrated in High-income Groups: High-income individuals often drive urban economic development, but they are also major contributors to per capita carbon emissions. This means that decarbonization efforts may conflict with the interests of high-income groups, requiring strategies to manage this challenge.

e. Net-Zero Carbon Transition is a Long-term Assignment: Achieving net-zero carbon emissions is a long-term task that requires substantial financial and technological investments. This may be constrained by limited resources and insufficient investments, necessitating sustainable fundraising plans.

f. Global Cross-institutional Collaboration Faces High Technological and Implementation Thresholds: Global cooperation needs to span different political, economic, and technological systems, adding complexity to collaboration. Additionally, the high technological thresholds required for implementing decarbonization plans demand more research and innovation.

g. Global Cooperation Efforts Need Strengthening: Despite some progress, global cooperation efforts are still insufficient. Closer global collaboration is needed to collectively address the challenges of climate change, including international policy formulation, technology sharing, and resource allocation.

To address these challenges, a comprehensive set of measures is needed, including improvements in data sharing and assessment, promotion of cross-sectoral collaboration, increased public awareness, differentiated decarbonization strategies, sustainable fundraising, promotion of technological innovation, and strengthened international cooperation. Faced with these challenges, a sense of urgency must be maintained, and proactive actions are required to achieve global carbon emission control goals. Only through collaboration, innovation, and steadfast commitment can we pave the way for future sustainable development and mitigate the impacts of climate change.

1.3 Opportunities Arising from Digital Development

Figure 1-29: 2023 China International Big Data Industry Export

Source:https://img-nos.yiyouliao.com/alph/51bbb71931b4dee8dcba550051c86f5f.jpeg?yiyouliao_channel=msn_image

In recent years, major countries worldwide have recognized the transformative potential of digital technologies, including big data, artificial intelligence, 5G, blockchain, the Internet of Things (IoT), and cloud computing. These technologies not only play a significant role in advancing the digital economy but also have the potential to guide a comprehensive transition in governance models. In the realm of net-zero carbon transition, this wave of digital technology brings unprecedented opportunities and challenges.

At the same time, we must acknowledge the real issues facing the achievement of the "dual carbon" goals:

a. The main track of digital technology development has not yet fully covered global environmental governance-related fields.

b. A cross-border cooperation system among countries for addressing climate change actions has not yet been established.

c. The conditions required for the rapid application of digital technological development to climate action pose issues of cost and timeliness.

The opportunities arising from digital development lie in finding new connection points and forces of action for digital technologies to address these challenges:

a. Data-Driven Urban Planning: Digital technologies, especially big data and artificial intelligence, provide unprecedented capabilities for urban planning. By analyzing large datasets, urban planners can better understand resident behavior, needs, and travel patterns. This profound insight aids in formulating more intelligent and efficient urban planning schemes to meet the demands of future urban growth while minimizing resource wast.

b. Precision Management of Carbon Emission Reduction: Digital technologies play a crucial role in carbon emission reduction. Blockchain technology can be used to track and verify carbon emission rights transactions, ensuring transparency and compliance. Simultaneously, IoT technology can monitor and optimize a city's energy usage, helping cities achieve more efficient energy utilization and reduce unnecessary carbon emissions.

c. Intelligent Energy Supply: 5G and cloud computing technologies enable better management of energy supply in cities. Smart grids and energy storage systems can better integrate renewable energy, achieving sustainability in energy supply. This not only helps reduce carbon emissions but also enhances the city's energy resilience, reducing dependence on traditional energy sources.

d. Promotion of Green Consumption: Digital technology can promote the widespread adoption of green consumption. Through online platforms and applications, residents can more easily access information about sustainable products and services. This helps drive the adoption of clean energy, reduce demand for high-carbon products, and ultimately lower the city's overall carbon footprint.

Figure 1-30: C40 CITIES Global Cities Climate Alliance

Source: https://cdn.shortpixel.ai/spai/q_glossy+w_493+h_501+to_webp+ret_img/www.c40.org/wp-content/uploads/2022/11/Copy-of-JUAN7312JUAN7312-1-scaled.jpg

e. Enhanced Urban Governance: Digital technology improves the efficiency and transparency of urban governance. Through data monitoring and feedback, city administrators can better understand the city's operational status and take targeted measures to address issues. This real-time feedback helps cities better respond to environmental challenges, including climate change and natural disasters.

f. Opportunities for Global Cooperation: Digital technology also provides new ways for global city cooperation. Cities can share best practices, data, and technological solutions to collectively address challenges of climate change and carbon reduction. Blockchain technology and smart contracts can ensure transparency and credibility in international cooperation.

In summary, digital technology presents unprecedented opportunities for urban net-zero carbon transition. By judiciously leveraging these technologies, cities can more effectively achieve "dual carbon" goals, enhance urban sustainability, reduce carbon emissions, improve residents' quality of life, and foster global cooperation among cities to collectively address the challenges of global climate change.

1.3.1 Global Development and Trends in Digital Technology

Digital technology stands as a key driving force in today's world, exerting profound impacts across various industries. From cloud computing to artificial intelligence, from the Internet of Things (IoT) to blockchain, from biotechnology to gene editing, digital technologies are continuously evolving, bringing new opportunities and challenges to the global landscape.

Recently, the Alibaba Research Institute and Zhupu AI jointly released the "2023 Global Digital Technology Development Research Report." Leveraging data from the A Miner technology intelligence platform and employing bibliometric methods, the report creates a "portrait" of the forefront of digital technology research, revealing the level of innovation and summarizing the top ten global trends in digital technology for 2023. These trends undoubtedly play a crucial guiding role in the future development of digital technology.

However, it is important to note that, despite the numerous innovative technology tracks and application scenarios in the field of digital technology, there is still significant room and potential for development in the application of these technologies to urban climate change response. Therefore, it is necessary to explore in-depth how digital technology can provide revolutionary support for carbon production, carbon reduction, and carbon management applications in urban settings to accelerate the upgrade of global climate action.

Firstly, cloud computing technology has become the cornerstone of the digital era. It provides large-scale computing and storage resources, enabling organizations to manage and analyze data more efficiently. Cloud computing not only reduces costs but also offers flexibility, allowing businesses and governments to better adapt to rapidly changing demands. This is particularly crucial in the low-carbon sector as it supports tasks such as energy management, carbon emission monitoring, and climate modeling.

Secondly, Artificial Intelligence (AI) and Machine Learning (ML) technologies are profoundly transforming various fields. AI and ML can extract information, perform pattern recognition, and automate decision-making from big data. These technologies hold immense potential in areas such as urban

Rankings	Advanced Tech	TOP1%Number of Papers	Number of high-value patents	Frontier Index	Average Year of Publication
1	Bio Big Data	694	13	0.99	2017
2	Generative Adversarial Network Algorithms	141	150	0.98	2019
3	Immersive Extended Reality Entertainment Platform	54	1153	0.95	2018
4	Quantum Computers	81	1143	0.94	2017
5	AI Decoding Protein Architecture Mobile Edge Computing Networks	160	185	0.93	2018
6	Mobile Edge Computing Networks	175	1686	0.92	2018
7	Interpretable AI	126	41	0.92	2019
8	Federated Learning	66	13	0.91	2020
9	Energy Blockchain	292	293	0.90	2018
10	Federated Learning	67	33	0.86	2019

Figure 1-31: 10 hot frontier technologies in the field of digital science and technology

Source: "2023 Global Digital Technology Development Research Report" planning, energy management, and environmental monitoring. For instance, intelligent transportation systems can optimize traffic flow, reduce congestion, and minimize energy wastage. In the energy sector, AI can aid in predicting electricity demand to optimize production and distribution.

Furthermore, the Internet of Things (IoT) technology connects billions of devices, bridging the real world with the digital world. These devices can monitor and transmit real-time data, including weather data, energy consumption, and environmental parameters. In the low-carbon sector, IoT can be used to monitor and manage renewable energy systems, achieving more efficient energy production and distribution.

Additionally, blockchain technology provides a decentralized and secure method of data recording. Widely applied in the financial sector, it also has the potential for carbon emission tracking and carbon trading. Blockchain can ensure transparent tracking of the source and usage of energy, thereby enhancing the sustainability of the energy market. Despite the enormous potential of digital technology in addressing climate change, there are currently significant challenges:

a. Fragmented Applications: Digital technology in climate change mitigation is often fragmented, not fully integrated into globally coordinated strategic actions. Additionally, technologies used in areas such as urban planning, energy management, and climate monitoring operate independently, lacking synergy and technological amplification, resulting in untapped potential benefits.

b. Lack of Global Coordination: Climate change is a global and open issue, yet the application of digital technology is often confined to specific technical or administrative boundaries. The absence of global coordination mechanisms and standardized approaches may lead to inconsistent data or technological interfaces, hindering cross-border collaboration.

c. Digital Gap: Some regions and communities may not fully leverage digital technology due to a lack of digital infrastructure or insufficient digital resources and capabilities. This digital divide could limit the comprehensiveness and fairness of climate change mitigation efforts.

d. Data Privacy and Security: Handling large amounts of sensitive data, especially when shared across borders, raises sensitive and crucial issues of data privacy and security. Concerns about privacy or security at the individual and national levels may restrict widespread collaboration and application of digital technology.

e. High Carbon Emissions from Digital Infrastructure: Despite the efficiency gains digital technology can bring, essential digital infrastructure such as data centers requires significant energy consumption to remain operational. This may conflict with low-carbon goals, necessitating parallel development of optimization and decarbonization strategies

Figure 1-32: ENI Green Data Center

Source: https://www.unesco.org/biennaleluanda/2021/en/eni for sustainability.

Therefore, to more effectively guide the use of digital technology in addressing climate change, it is essential to consider a series of measures:

a. Focus on Action Planning: Cities and nations need to formulate comprehensive strategies for digitalization and low-carbon development, ensuring the organic integration of various digital technology applications to collectively address the challenges of climate change.

b. Cross-Border Investment and Collaboration: Cities and businesses should increase investment in digital technology, including digital infrastructure, talent development, and research and development. Actively engaging in international cooperation, establishing international cross-border partnerships, and sharing best practices and experiences are crucial aspects of this effort.

c. Enhance Policy Support: Governments should enact relevant policies that encourage the sustainable development of digital technology while ensuring data privacy and security. Policies can also promote the widespread adoption of digital technology and reduce the digital divide.

d. Mobilize Social and Technical Resources: Emphasize the cultivation of social value to guide the transition of social resources into support for climate change mitigation. Simultaneously, raise the digital literacy and awareness of climate action among urban planners, engineers, and decision-makers to better understand and apply digital technology to address climate change issues.

e. Consider Sustainability: While promoting digital technology, it is crucial to prioritize sustainability, including energy efficiency and carbon footprint. For instance, adopting green data center technologies and renewable energy sources can mitigate the environmental impact of digital technology or facilities.

In summary, the rapid development of global digital technology is redefining the future of net-zero carbon transition. The multidimensional progress of these technologies presents new opportunities for key areas such as urban carbon production, carbon reduction, and carbon management, empowering cities to more effectively address the challenges of climate change. Globally, in the face of escalating climate change, countries are actively taking actions to stabilize global temperatures and mitigate the impacts of climate change.

In this process, achieving net-zero emissions has become a crucial goal, with digital technology innovation recognized as a key pathway to realizing this objective. This necessitates collaboration among governments, industries, and the academic community to collectively drive the application of digital technology in urban climate action. Only through innovation and collaboration can we harness the power of digital technology more effectively, enhance urban climate resilience, reduce carbon emissions, and make a greater contribution to global climate action.

1.3.2 Digital Technology Facilitate Urban Net-Zero Carbon Transition

Digital technology plays a crucial role in the urban net-zero carbon transition, actively leading the development of sustainable living environments. It not only integrates technology with human values but also promotes the symbiosis between cities and nature, aiming to achieve the goal of urban net-zero carbon transition.

In the pursuit of dual carbon goals, digital technology possesses unique potential to contribute to path planning, practical methods, data monitoring, measurement and feedback, as well as evaluation. It also helps coordinate a city's energy supply and consumption, promote the use of clean energy, drive the development of innovative energy models and formats, encourage green consumption, enhance urban governance efficiency, and play a crucial role in various domains. The capabilities conferred by digital technology, through collaborative efforts, contribute to emission reduction, improved energy

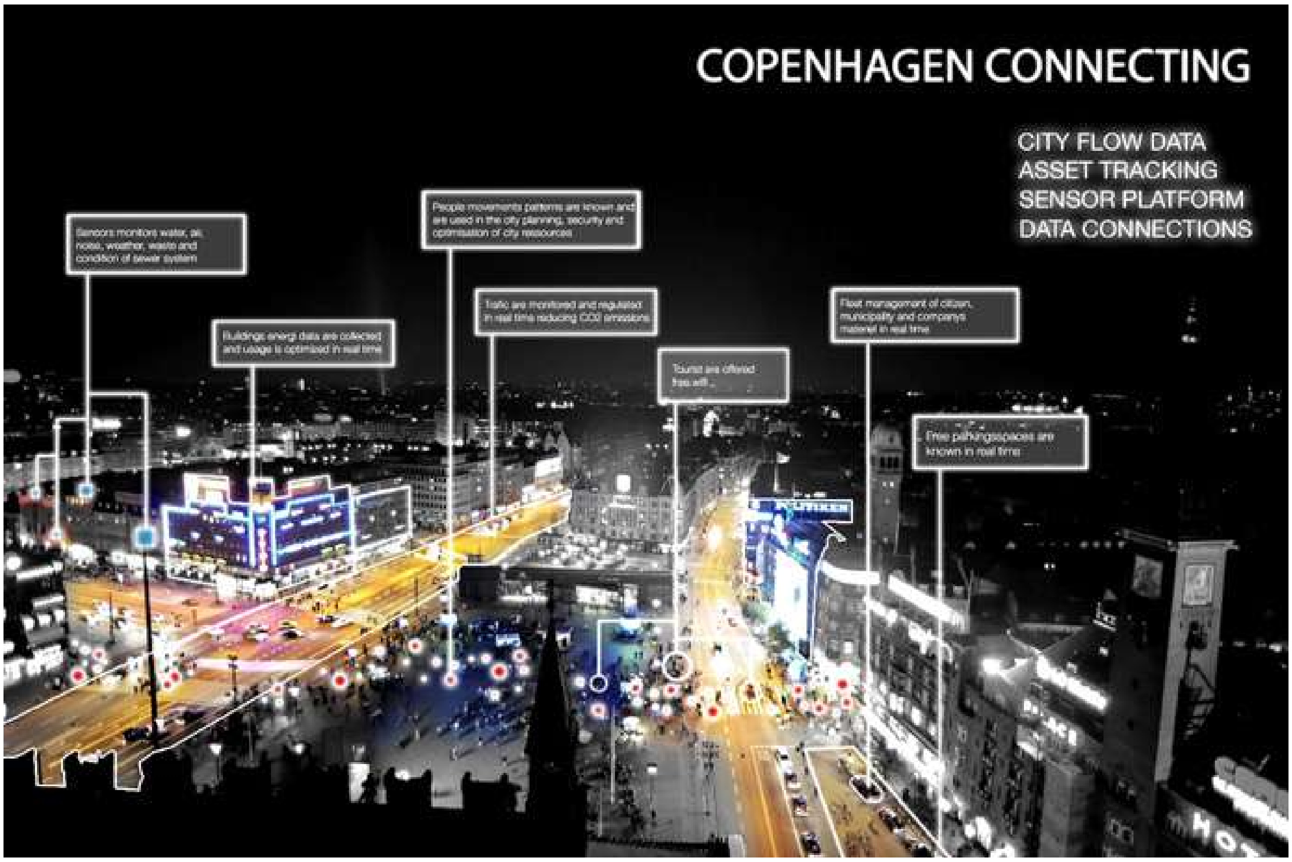


Figure 1-32: Copenhagen Smart City Linkr

Source:http://www.europe-re.com/uploads/europe/post_content_images/copenhagen-capacity-smart-city-of-the-future-3_August_2015_0.jpg

efficiency, and enhanced urban resilience, providing innovative solutions for achieving future urban net-zero carbon goals. Digital technology will support the realization of urban net-zero carbon goals in the following aspects:

a. Developing New Energy Technologies to Increase Efficiency and Reduce Greenhouse Gas Emissions: The application of digital technology can accelerate the research and deployment of new energy technologies, such as smart grids and the integration of clean energy like solar and wind power. Through big data analysis and artificial intelligence, we can better manage and optimize the energy supply chain, reduce energy waste, and decrease greenhouse gas emissions. Digital twin technology can simulate a city's energy system, identifying opportunities to improve energy efficiency and solidifying a city's transition to net-zero carbon. For example, Copenhagen, the capital of Denmark, successfully implemented a smart grid system, effectively integrating wind and solar energy to stabilize its energy supply.

b. Revitalizing Urban Infrastructure, Enhancing Fine Governance, and Improving Public Service Efficiency: Digital technology not only improves urban energy systems but also enhances the operational efficiency of urban infrastructure. Digitized infrastructure such as smart traffic management, intelligent buildings, and smart water systems can monitor and adjust the use of city resources, reducing energy waste and environmental impact. Additionally, digital city planning tools can help decision-makers better understand how cities operate, enabling finer governance and improving the quality and efficiency of public services. Shenzhen, China, utilizes big data analysis and intelligent traffic systems to manage city traffic. Through mobile applications and traffic monitoring devices, the city can monitor traffic flow in real-time, adjust traffic signals and routes as needed, reducing congestion and vehicle emissions.

c. Promoting Green Lifestyle Values, Encouraging Public Participation, and Anchoring Ecological and

Humanistic Awareness: Digital technology plays a crucial role in promoting green lifestyles and increasing public participation. Smartphone applications and social media platforms enable city residents to access information and resources related to sustainable living more easily. Additionally, digital technology supports sustainable transportation, such as ride-sharing platforms and intelligent traffic management systems, thereby reducing a city's carbon emissions. Simultaneously, digital technology helps city managers better understand citizen needs to meet expectations, anchoring ecological and humanistic values. Amsterdam, as the cultural and artistic center of the Netherlands, successfully integrates ecological themes into art and culture through digital cultural activities and interactive exhibitions, attracting more citizens to participate in environmental protection activities.

d. Driving the Development of Green Finance, Green Product Innovation, and Promoting Low-Carbon Economic Development: The application of digital technology in the financial sector also contributes to the realization of urban net-zero carbon. Digital financial platforms facilitate the development of green finance by providing funding support for investments in renewable energy and sustainable infrastructure. Moreover, digital technology helps track and verify the environmental performance of green products, encouraging consumers to purchase more environmentally friendly goods and services. This trend is likely to encourage more businesses to adopt low-carbon economic models, propelling cities toward net-zero carbon goals. Lon-

Figure 1-33: Shenzhen smart transportation Experience block

Source: http://news.sznews.com/pic/2020-08/26/c0dced86-0789-44bc-96aa-d01fd211513f55fe90c2-1b9b-489c-a0fe-655356cfce92.png

Figure 1-34: Amsterdam Green Culture Festival

Source:https://i0.wp.com/thecitylife.org/wp-content/uploads/2022/10/JulieLemberger-4429.jpg?resize=1024%2C683&ssl=1

Figure 1-35: Shenzhen smart transportation Experience block

Source:https://iigf.cufe.edu.cn/__local/A/9E/78/ECA17CC46807B4E6161679E77E8_931815F0_24BA0.jpg

Figure 1-36: Amsterdam Green Culture Festival

Source:https://cn.unionpay.com/upowhtml/cn/templates/material/7885004da382485e8bde5a0ba000fdd3/1689217854945.png don, for example, has established a carbon market using blockchain technology, making it easier for businesses and investors to finance and support sustainable projects such as renewable energy and energy efficiency improvements.

e. Driving Innovative Business Models, Encouraging Green Consumption, and Achieving Zero-Carbon Economic Soar: The rise of digital technology has also spawned many innovative business models that contribute to the realization of zero-carbon economies in cities. Industries such as the sharing economy, electric transportation, and smart city solutions are thriving, providing new low-carbon alternatives for cities. Digital technology can also help businesses implement carbon tracking and emission reduction plans, steering them towards more environmentally friendly practices. These measures not only contribute to reducing a city's carbon emissions but also lay a solid foundation for the sustainable growth of urban economies. For instance, Shanghai has established a carbon-inclusive mechanism, connecting with the Shanghai carbon market to encourage local enterprises to purchase carbon-inclusive emission reduction credits for carbon compliance. Additionally, it encourages enterprises, individuals, and large event organizers to purchase carbon-inclusive emission reduction credits to achieve carbon neutrality.

The development of digital technology in the field of urban net-zero carbon transition not only improves the energy efficiency and environmental performance of cities but also promotes the popularization of green lifestyles, stimulates public participation, accelerates the development of green finance, and drives the emergence of innovative business models. Digital technology innovation is a key opportunity for addressing climate change and achieving urban net-zero carbon transition. With confidence in the power of digital technology, we can collaboratively shape a more sustainable and environmentally friendly urban future. To ensure the maximum potential of digital technology is unleashed, comprehensive measures in policy, technology research and development, and social participation are needed to build more sustainable cities and leave a better living environment for future generations.

Digital Innovations for Net Zero Carbon Cities

Cities are responsible for a significant amount of carbon emissions. However, they are also battlegrounds for addressing climate change by taking mitigation actions (Pashkovskaia and Lucini, 2023).

02

Chapter 2

Cities are responsible for a significant amount of carbon emissions. However, they are also battlegrounds for addressing climate change by taking mitigation actions (Pashkovskaia and Lucini, 2023).

2.1 Building & Housing

Approximately 40 percent of carbon (CO_2) emissions globally are generated by the building sector (Anon, 2023; Li, 2023). The carbon emission of building and housing mainly comes from two sources, building materials and construction (embodied carbon) and building operations (operational carbon) (Visnick and Caulfield, 2021). The following sections will discuss how digital technologies help with the realization of lower carbon emissions from both sources.

2.1.1 Energy Management in Design, Construction and Operation Stage

a. Design Stage: The life-cycle of building and housing starts from design, which might be the first stage where digital technologies play a part in minimizing carbon emissions by avoiding potential carbon emissions in the following construction and operation stages. To be specific, for instance, big data and artificial intelligence (AI) can help with spatial calculations and analysis on terrains and landforms. An optimized design solution with a balance between excavation and filling volume can then be worked out (Smart City Standards Work Group of China National Information Technology Standardization Commission, 2022). Using AI-driven analysing tools, the design of space utilization as well as airflows in a built environment can be optimized (Anon, 2023), which result in less energy consumption in future operation.

b. Construction Stage: At the construction stage, BIM is particularly valued in reducing carbon footprint. As an approach serving the life-cycle of a building, BIM can manage the energy consumption (Bortolini et al. 2022) by tracing and monitoring the carbon footprint of building materials from manufacture, transportation and utilization (Mah et al. 2011). It also enables spatial computations on potential conflicts in practical installation or construction steps so that it improves the process with less material waste (Wang, 2022), which contributes to carbon reduction in an indirect way.

c. Operation Stage: Carbon emissions from building operations account for about 28% of the overall. Therefore, the operation stage is the key to cutting off the emissions. A variety of digital technologies are applied to support carbon reduction in this stage, mainly by optimizing the energy supply for lighting, heating and cooling.

To be specific, smart sensing terminals provide real-time monitoring data of environmental parameters such as temperature, humidity, carbon dioxide concentration and people movement (Chen et al. 2023; Sacke, 2021). The data are shared via network or the sensors are connected to Internet of Things (IoT) so that the stakeholders can better control energy usage and plan predictive maintenance. Using big data analysis, the monitoring data can also be used to estimate energy demands in a certain period. Digital twins as a technology of structuring a virtual model of a real subject with real-time data interchange (Tao et al. 2022) can model, analyze, and make decisions on maintenance and sustainability in different scopes. It is not only able to monitor and manage the energy consumption of the whole

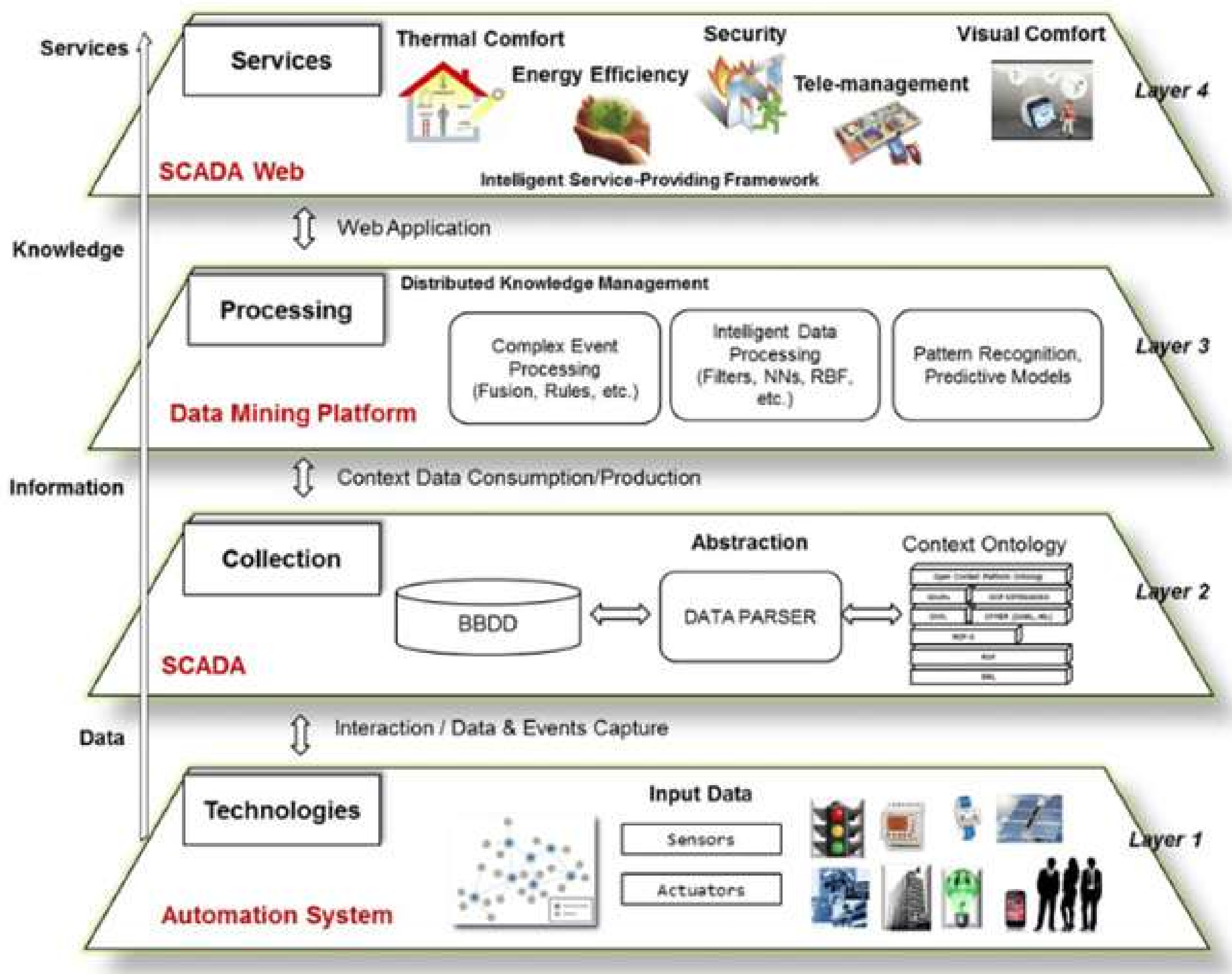


Figure 2-1 common architecture of smart building management system (Moreno et al. 2014)

Source: Sensors,2014,14(6).

building in daily operation by developing a real-time digital model but also works in a microscope by predicting the schedule of replacing physical prototypes (Sacke, 2021). 5G and IoT are used for faster and higher capacity data transmission with remote management and control of connected devices (Anon, 2023).

2.1.2 Smart Heating/Cooling Supply

The supply of heating and cooling is a part of building operation, but it will be separately addressed as it takes up a high percentage of the overall energy consumption.

In terms of a single building unit, digital technologies help with carbon emission reduction by working as an integrated smart building system and controlling Heating Ventilation and Air Conditioning (HVAC). The common architecture of such a system contains several layers. Smart facilities with sensing and interacting capabilities capturing heterogeneous data, such as environmental data and energy consumption data, are in the bottom layer. The second layer is responsible for data collection and unifying data formats. The next layer for data processing deploys different intelligent rules based on the final application situations in the building context. For example, a mechanism based on Radial Basis Function Networks and Particle Filter is implemented for indoor localization and an optimization method based on Genetic Algorithm is taken for calculating optimal comfort conditions (Moreno et al. 2014). The application situations are presented in the last layer, where the smart management of thermal comfort dominates in the decrease of energy consumption during the building operation.

2.2 Urban Water

Energy is used in numerous processes of the urban water sector, which is usually underestimated (Rothausen and Conway, 2011). The electrical energy consumption for drinking water has been doubled in China since 2000 (Liu et al. 2022). Since urban water is facing increasing challenges, for example, water scarcity, extreme weather, and infrastructure maintenance (IWA and Baidu, 2022), energy consumption and carbon emission for urban water will be predictably higher. There have been systematic resolutions on smart water management applicable for multiple scenes. In order to make it clear how digital innovations can help with lower or even nexus carbon emissions in the water sector, this section will explain which and how the technologies are used in several water supply and treatment stages.

2.2.1 Water Resource Allocation

It is proposed to build up an architecture of smart water management and improve the capability of water allocation in the 14th Five-Year Plan (China Mobile, 2023). On a macro scale, it aims to develop a national-level data platform with virtual models of the main domestic water systems using digital twins to optimize the overall planning of water resource

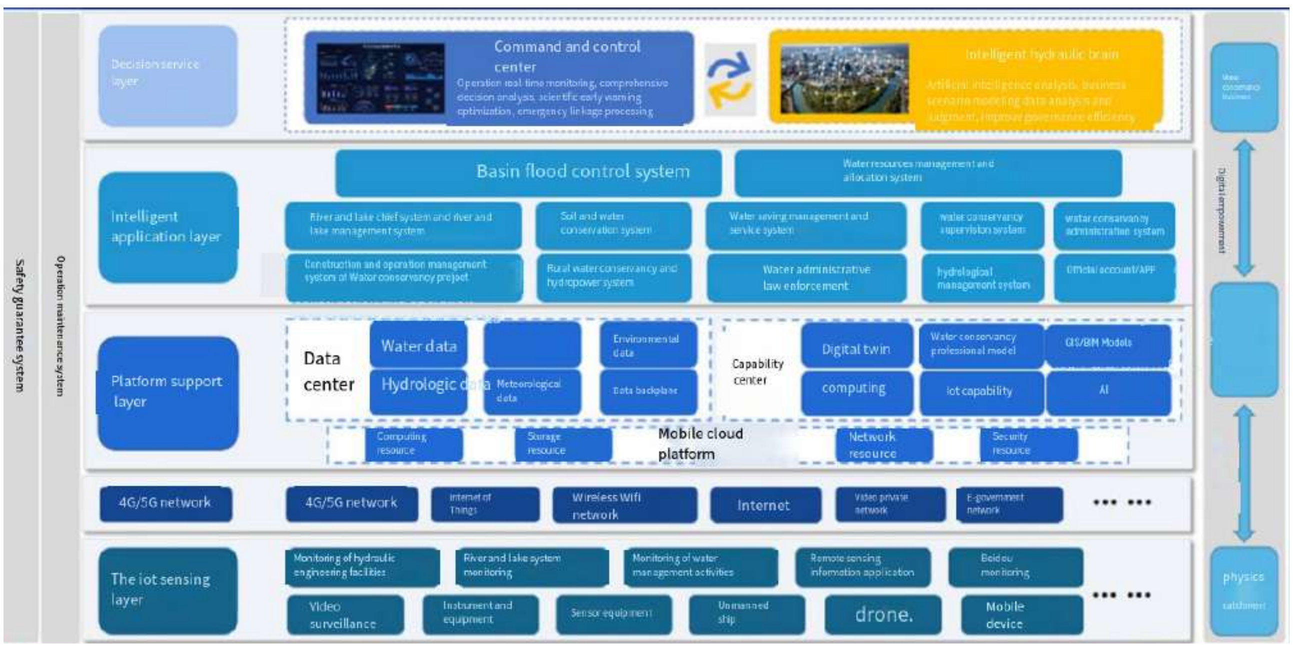


Figure 2-2 Example architecture of smart water management system

Source: China Mobile. 2023

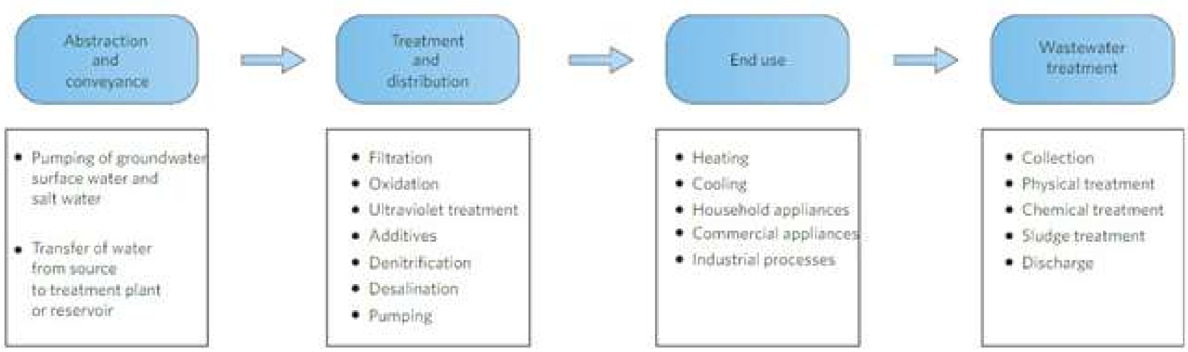


Figure 2-3 a conceptual model of water-sector processes involving energy use

Source: Rothausen and Conway, 2011

usage, which avoids plenty of potential carbon emissions by water conveyance in advance.

Digital technologies also lower carbon emissions in water resource allocation on a regional scale. Sensor networks combined with artificial intelligence enable water flow monitoring. Big data analytics and artificial intelligence can explore and recognize rules or patterns from large amounts of time series data. This can be used for predicting water usage amounts. A variety of algorithms can be applied to optimize the operation of reservoirs by setting the operating parameters of the pump, formulating the pumping schedule, and optimizing the water supply plan (IWA and Baidu, 2022).

2.2.2 Operation and Maintenance of Water-Supply Networks

Water conveyance and distribution also involve in energy use and carbon emissions. However, poor maintenance of water pipe networks may result in low efficiency of water supply as well as energy use. Poor maintenance of water pipe networks is the most important reason for the largest waste of water resource (IWA and Baidu, 2022). The following content will briefly explain how digital technologies help with the operation and maintenance of water-supply networks by managing pipe pressure and controlling leakage.

By collecting historical data of the water supply network (such as pipe ages, pipe materials, widths and depths) and external real-time data (such as local precipitation, temperature and transport volume), the deep neural network training is used to generate pressure management model of pumping stations. The model is applied for adjusting the frequency parameters of the motors in pumping stations and setting warning thresholds of pipe pressure and water flow so that potential accidents like pipe bursts can be avoided(IWA and Baidu, 2022).

Traditional acoustic monitoring methods are currently widely used in the water supply industry. However, such methods may be limited when being applied to detect tiny leakage places. Singular Spectrum Analysis, which is a nonparametric adaptive method, can decompose and reconstruct the trajectory matrix of the time series and extract different component sequences in the time series data. This method combined with signal processing technologies can recognize sound characteristics made by tiny leakages(IWA and Baidu, 2022).

In addition, pressure sensors, DMA zoning metrology, GIS, and big data analysis techniques can analyze the amount of water leakage status and locate the leakage place in different spatial and temporal scales. Since there is often a lack of stress data on water pipes, unsupervised learning methods are applied. For instance, density-based clustering is used to identify data that lose spatial correlations due to pipe burst accidents(IWA and Baidu, 2022).

2.2.3 Wastewater Treatment

The most carbon emission in the water sector is from wastewater treatment, excluding the end-use section (Rothausen and Conway, 2011; Zheng et al. 2023). This section will mainly introduce how digital methods improve treatment efficiency with lower energy use.

The activated sludge method is the mainstream process of sewage treatment, and the concentration of dissolved oxygen in the aeration tank is a key process parameter. In order to better regulate dissolved oxygen concentrations, PI or PID control strategies are applied with multiple solutions improving their adaptability (such as Fuzzy adaptive PID control, and model prediction control) (SIEMENS, n.d.). Neural network algorithms (such as backpropagation, robust adaptive, radial basis function) are also used for parameter adjustment (IWA and Baidu, 2022). Thus the aeration volume can be controlled more precisely by managing the process parameters, which not only guarantees the quality of the treated water but also minimizes the total energy consumption.

As water reuse is becoming a widely-used way of resource circulation to increase water usage efficiency (50LHome, 2021), there is a growing importance of water quality monitoring. Artificial intelligence technology enables the prediction of concentrations of multiple chemicals, such as trihalomethanes, chlorine, and biomass. By training a neural network on the relationships between water quality characteristics and chemical monitoring parameters combined with Bayesian sequential analysis, potential pollution events can be predicted and avoided in advance (IWA and Baidu, 2022).

2.3 Urban Mobility

There is approximately 22% of global CO_2 emissions by transportation sector (Visnick and Caulfield, 2021). The key to achieving green and low-carbon urban mobility is intelligent transport systems and smart charging.

2.3.1 Transport Management

An intelligent transport system enriches commuters with prior information about real-time traffic information and enables local traffic authorities to optimize traffic management strategies, therefore it improves transport efficiency and reduces energy waste by road congestion.

The common architecture of intelligent transport systems consists of several layers. The base layer where sensing devices are located is used for data collection. The hardware includes vehicle identifiers, vehicle locators, sensors and cameras. Data on traffic count, travel speed, vehicle weight and time delays are collected and then processed by error rectification, data cleaning, data synthesis and adaptive logical analysis (Choudhary, 2019). With potential support from other public data, the final data outputs inform travellers on real-time traffic situations, such as travel speeds of different transportations, accidents on roads, and optimized route choices. In this way, the carbon emissions of transport can be reduced as the traffic efficiency is improved.

2.3.2 Smart Charging System

A reasonably planned charging system can reduce energy consumption and carbon emissions. Establishing an accurate spatial-temporal model of charging demand is the premise of analyzing the interactions between electric vehicles and the grid, which is the first step of making a plan for locating charging facilities. Big data and satellite remote sensing are used to analyze and simulate traffic data, travel mode and charging demand. These enable the simulation of spatial and temporal charging demands to better plan locations and numbers of charging facilities (Xing et al. 2020).

[vehicle as energy tank returning energy to the grid]
The key concept of Vehicle-to-Grid (V2G) is to regard Electric Vehicles (EVs) as a part of the grid, which serve as mini-size energy tanks. EVs can generate electricity, yet the generated energy is unused 90% of the time when EVs are in a parking state. V2G sends the stored power to the grid so that it helps balance grid loads by “peak shaving” (sending power to the grid when demand is high). On the other hand, V2G also contributes to lower carbon emissions by “valley filling”, which is charging at night when the energy demand is low. It is also the time when the energy generation is mainly from renewable sources so that it benefits to carbon reduction further.

2.4 Urban Waste and Circularity

Waste is the fourth largest source sector of emissions, accounting for 3% of total greenhouse gas emissions in 2017 (Anon, 2020). However, the emissions from waste management tend to grow according to the data from the UK government (Burrows, 2022). Therefore, it is important to put “3R” principles into practice, which aim to enhance resource reuse, reduce the waste amount and improve recycling efficiency. There is a variety of ways in which digital technologies can help, for example predicting waste generation patterns, navigating disposal facilities and optimizing combustion methods (Vyas et al. 2023). The following section will introduce how digital technologies help with waste recycling and sorting, which are two innovative scenes where digital technologies contribute to urban waste and circularity.

2.4.1 Waste Recycling

An incentive mechanism can be created by digital methods to encourage recycling. Using technologies such as data sharing, databases and IoT, the collection pattern of recyclable wastes can be analysed and the prices can be thoroughly adjusted (Zhou et al. 2021). This can make a balance of collection amount of different types of waste and keep recycling attractive in terms of economic payback.

2.4.2 Waste Sorting

Diverting recyclable waste from municipal solid waste is important to reduce the total waste amount. Digital methods such as image recognition and machine learning can help with the sorting process.

Image recognition and machine learning as diffusions of AI are applied for sorting waste. According to the existing literature, the most commonly utilized artificial algorithms are linear regression (LR), genetic algorithm (GA), support vector machine (SVM), artificial neural networks (ANN), and decision trees (DT). Using AI algorithms and smart cameras, nuances of the same materials can be accurately distinguished so that the efficiency of on-site waste classification is improved (Vyas et al. 2023). Hence it benefits the recycling of valuable subjects as secondary raw materials for manufacturing, the decrease of the total amount of waste to be filled or combusted, and the control of accident and health risks of frontline workers (Kurniawan et al. 2023).

In addition, digital methods can also contribute by optimizing waste collection routes. The waste trucks equipped with IoT can generate and transmit real-time data. Meanwhile, the filling level of containers is monitored by smart sensors (Kurniawan et al. 2023). The collected data can be synthesized and then an optimal solution for waste disposal location is advised.

2.5 Urban Energy

CO_2 emissions from energy combustion and industrial processes accounted for 89% of energy-related greenhouse gas emissions in 2022 (Huawei and Deloitte, 2021), hence energy is a key area that requires particular attention to managing and controlling the emissions. What makes energy even more interesting is its dual roles. It is both a scene where digital technologies are applied for carbon reduction, but also a tool serving as mitigation methods in other scenes during the process of power supply for building and housing, urban water, transportation and waste management.

2.5.1 Smart Grid

A smart grid is an automated electricity supply network. It connects electricity suppliers, transmission networks and end users and monitors the real-time mutual flow of electricity and information from the power plants to user terminals (Yu and Luan, 2009). A smart grid is significant to expand the use of renewable energy and create a more sustainable energy structure.

Digital technologies are employed by a smart grid to better match the supply and demand of electricity in real-time while minimizing costs and maintaining the stability and reliability of the grid (Drtil et al. 2023). It mainly requires seven technical areas to set up a smart grid, including flexible network topology, Integrated Energy and Communications Systems Architecture (IECSA), Fast Simulation and Modeling (FSM), Distributed Energy Resources (DER), Advanced Distribution Automation (ADA), Intelligent Electronic Devices (IEDs) and Advanced Metering Infrastructure. Digital technologies involve in each of the above, especially ADA and IEDs (Yu and Luan, 2009).

Digital technologies also dominate in the application of smart grids. The use of AI, IoT, big data and other advanced technologies can carry out intelligent maintenance of smart grids. Based on the IoT technology, it realizes line monitoring, equipment inspection and real-time control, and improves failure responses. Cloud computing and big data technology are used to construct a “heavy overload early warning model” to effectively predict the overload of electricity distribution and transformation With data analysis and machine learning, it realizes qualitative assessment and automatic intervention of the grid by cause analysis, rapid response and accurate positioning (China Academy of Information and Communications Technology, 2021).

2.5.2 Energy Internet

While a smart grid focuses on information and intellectualization of the grids, a concept of Energy Internet is proposed as an internet-based solution for energy issues by integrating information and power flows, which can be considered as version 2.0 of smart grids (Cao and Yang, 2013).

The technologies used for Energy Internet are similar to those for smart grids, such as big data, cloud computing and smart controllers, as well as wired networks (IP4/IPV6), wireless networks (5G, NB-IoT), Human-Computer Interface (HCI) etc. By equipping itself with digital technologies, Energy Internet can effectively overcome problems such as volatile power outputs and abandonment of light or wind to increase the percentage of renewable energy use (Alibaba Cloud Innovation Center and Forward, n.d.).

In terms of application and operation, energy internet is enhanced by digital techs as well. For example, they play a role in user-side energy consumption and energy storage. In terms of energy consumption, clustering and classification algorithms can be used for reasonably pricing the energy and optimizing of energy structure (China Academy of Information and Communications Technology, 2021). In addition, there is a large number of scattered energy in idle batteries as storage resources on the user side. Cloud-based Battery Energy Storage Systems (BESS) can decide when to store and release energy. It helps with shaving peak, saving extra renewable energy and serving as a cost-effective energy supply. In particular, energy stored by houses and buildings can also be accessed into grids, turning them into energy-supply units and strengthening the resilience of the grids.

2.6 Carbon Management

The use of digital technologies can significantly contribute to carbon accounting, carbon trading and carbon financing.

At present, reliable carbon accounting is a necessary presumption of carbon trading and financing (Alibaba Cloud Innovation Center and Forward, n.d.). Unmanned aerial vehicles (UAVs), satellites and AI are applied to build up a real-time smart monitoring system of carbon dioxide emissions with reduced human errors and improved timeliness. Big data, clouding computing and IoT offer a more accurate method to track the life-cycle of carbon footprints of products (Anon, 2022).

Carbon trading and financing are also enhanced by innovative applications of digital technologies. Blockchain is a distributed database that can set up a real-time and trustworthy transaction environment and maintain secure records of transactions. The immutability of blockchain can guarantee data privacy of carbon trading and financing and make carbon transactions trackable (Smart City Standards Work Group of China National Information Technology Standardization Commission, 2022). Big data analysis can provide carbon market forecasts and pricing strategies (Liu et al, 2023), which improves the efficiency of carbon trading and financing. Meanwhile, knowledge graph and deep learning can be applied to developing a credit system for carbon trading and financing (China Academy of Information and Communications Technology, 2019). With reliable endorsement of credit reporting, services such as bank credits and financing guarantees can be offered to enterprises, which accelerates the efficiency of carbon trading and financing.

2.7 Summary

This chapter describes how digital technologies as innovative methods to help with building up a net zero carbon city in six tracks.

From the perspective of technology, digital technology empowers the construction of net-zero carbon cities by reducing unnecessary activities, as well as optimizing and dematerializing the process of construction and operation. Particularly, 5G and the IoT are the basis of information and communication. They support data collection and data transmission in the process of data monitoring and accounting (such as real-time data collection to support building operations and real-time data transmission of Energy Internet). Big data and cloud computing technologies empower algorithms and computility. They mainly contribute to scenario prediction and process simulation by data mining and data analysis (such as water resource distribution and operation and maintenance of water supply pipe networks). Artificial intelligence technology mainly supports decision-making optimization (such as water quality monitoring and garbage classification for wastewater treatment) through deep learning and trend analysis. Blockchain technology is mainly used in data trustworthiness and transaction incentive scenarios to support carbon management.

From the perspective of scenarios, digital technology supports the whole life-cycle in the building and housing scenarios, especially heating and cooling in the operation stage, to achieve carbon reduction. In the urban water scenario, carbon reduction is carried out by optimizing the allocation of water resources, streamlining the operation and maintenance of the water supply network, and optimizing the wastewater treatment process. In the transportation scenario, carbon reduction is mainly implemented by improving transportation efficiency through intelligent transport systems and new energy transportation facilities. In terms of urban waste and circulation, energy consumption is reduced by establishing an incentive mechanism and improving recycling efficiency. In terms of urban energy, digital

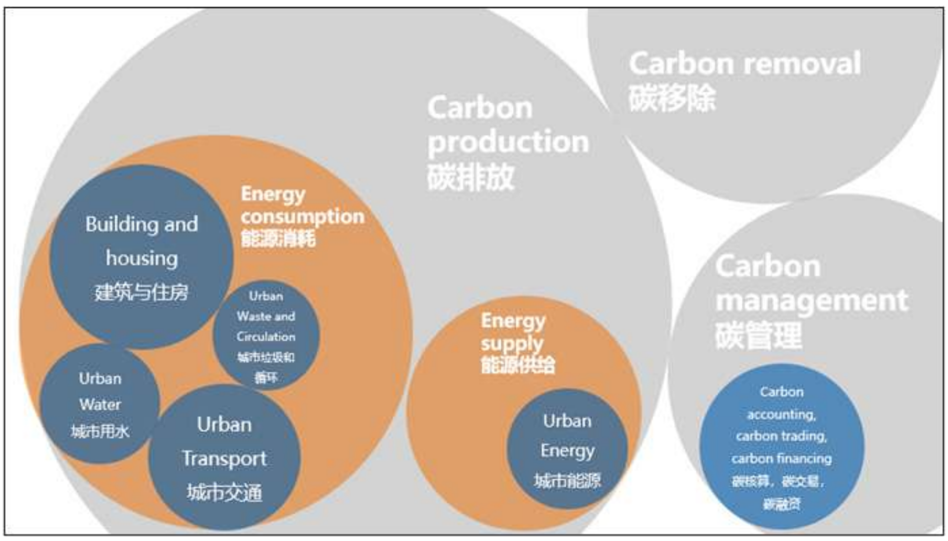


Figure 2-4 the relationships between the scenarios, energy supply and consumption, as well as carbon generation and reduction

Source: draw by author

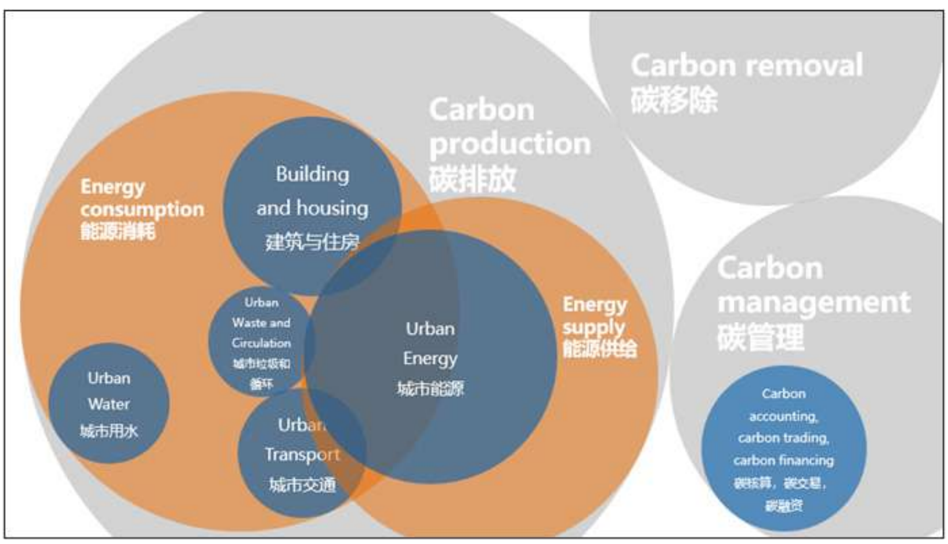


Figure 2-5 the reconstruction of the relationships between the scenarios, energy supply and consumption, as well as carbon generation and reduction

Source: draw by author

technologies promote the construction of net-zero carbon cities from the perspective of energy supply by improving the efficiency of traditional energy and solving the stability problem of renewable energies.

The following figures summarize the relationship among the scenarios,

track	scene	Specific scene	technology (and system, if applicable)	innovations
Building And housing	energy management in design, construction and operation stage	Design	**Big data, AI**	
		Construction	**BIM**	
		Operation	**smart sensors, big data, digital twins, IoT, 5G**	
	Smart heating/cooling supply	HVAC and energy consumption management in a single building unit	**IoT and data processing (smart building system)**	A mechanism based on Radial Basis Function Networks and Particle Filter; Genetic Algorithm
urban water	water resource allocation	optimizing the overall plan of water resource usage	**digital twins**	
		water flow monitoring	**sensors, IoT**	
		predicting water usage amount	**Big data, AI**	
		optimizing the operation of reservoirs	**AI**	SFNN; NGA
	operation and maintenance of water supply network	managing pipe pressure	**AI, sensors, big data**	Deep Neural Network
		detecting tiny leakages	**sensors, GIS, big data, AI algorithm**	nonparametric adaptive method
	wastewater treatment	controlling treatment processes	**digital twins, AI**	control algorithms, neural network algorithms
		monitoring water quality	**AI**	Neural network and Sequencial Baysian analysis method

track	scene	Specific scene	technology (and system, if applicable)	innovations
urban mobility	transportation management	improving transport efficiency	**sensors, wireless communication, big data, AI algorithms(and Intelligent Transport System)**	Wireless communication
	smart charging system	locating charging facilities	**big data, satellite remote sensing**	
		V2G	**communication and control technologies, 5G**	
urban waste and circularity	waste recycling	creating an incentive mechanism	**data sharing, database and IoT**	
	waste sorting	on-site waste classification	**AI algorithms, smart sensors**	Machine learning (Linear regression, Genetic algorithm, Support vector machine)
		optimizing waste collection routes	**IoT, data sharing, data processing**	
urban energy	smart grids	setting up smart grids	**flexible network topology, Integrated Energy and Communications Systems Architecture (IECSA), Fast Simulation and Modeling (FSM), Distributed Energy Resources (DER), Advanced Distribution Automation (ADA), Intelligent Electronic Devices (IEDs) and Advanced Metering Infrastructure**	
		maintaining smart grids	**AI, IoT, big data, cloud computing**	heavy overload early warning model
	energy internet	setting up energy internet	**big data, cloud computing and smart controllers,wired network (IP4/IPV6), wireless network (5G, NB-IoT), Human-Computer Interface (HCI)**	
		user-side energy consumption and energy storage	**AI**	clustering and classification algorithms, clustering and classification algorithms
carbon management	carbon accounting	carbon accounting	**unmanned aerial vehicle (UAV), satellite, AI, big data, IoT**	
	carbon trading and financing	setting up trustworthy trading environment	**blockchain**	
		providing carbon market forecasts and pricing strategies	**data analysis**	
		developing a credit system of carbon financing	**AI**	knowledge graph, deep learning

Figure 2-6 Summary of digital technologies and their application scenes

Source: draw by author

03 Digital Innovation Enabling Net Zero Carbon City Roadmap

This chapter will use digital innovation technologies represented by the Internet of Things, big data, cloud computing, and artificial intelligence, through a three-step roadmap of "mastering carbon data-formulating carbon strategies-smart carbon actions", to promote the digitalization, greening, and sustainable development of cities, and achieve the "carbon neutrality" goal.

Chapter 3

Summary

In 2022, global energy-related carbon dioxide emissions exceeded 368 billion tons, an increase of 0.9%. Of these, China's energy-related carbon dioxide emissions were 121 billion tons, which remained basically flat year-on-year, with a slight decrease of 0.2%, due to the impact of the COVID-19 pandemic.

Cities are the hubs of economic and industrial activities and the centers of consumption. They occupy less than 3% of the world's land area but are home to 56% of the world's population. By 2050, the proportion of the world's population living in cities is expected to rise to 66%. In addition, cities are consumers of resources, consuming 67%-76% of the world's energy and emitting 75% of the world's greenhouse gases.

The net-zero carbonization of Chinese cities is imperative under the backdrop of the "dual carbon" goal. However, "carbon neutrality" is not a one-size-fits-all solution. Therefore, the net-zero carbonization roadmap for cities to achieve "carbon neutrality" will also be a complex system engineering, a process of dynamic balance between carbon sources and carbon sinks. Therefore, the net-zero carbon city roadmap should be a comprehensive set of dynamic schemes that can systematically address the constantly changing factors of the implementation effects, implementation costs, and negative carbon technologies, forest carbon sink levels, etc. of energy-saving and carbon reduction technologies in various fields.

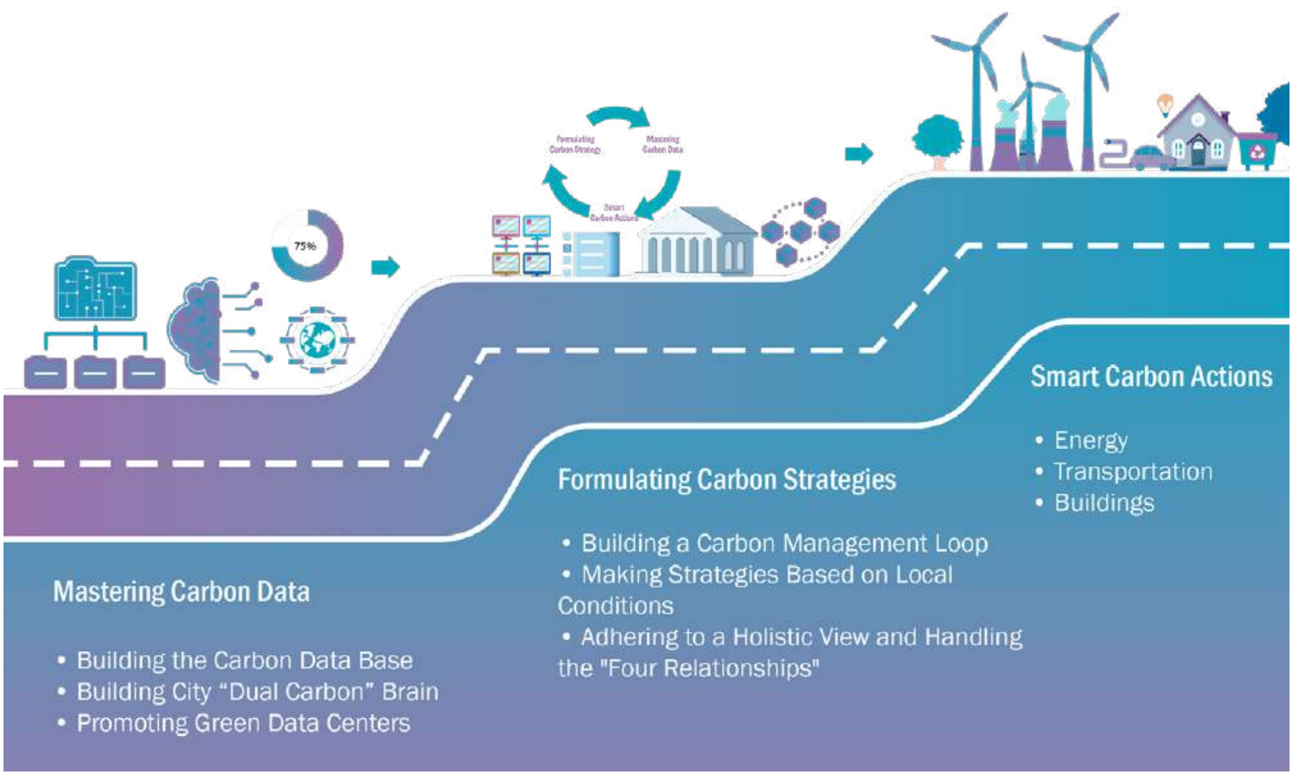


Figure 3-1: Roadmap of Net-Zero Carbon Transition

Source: Draw by author

3.1 Mastering Carbon Data

Cities are the hubs of economic and industrial activities and the centers of consumption. They are also the main units for government policy regulation. Compared with the national scale, cities can take more flexible and rapid measures to address climate change, making them the main participants in addressing global climate change.

From the perspective of overall planning, the carbon neutrality of cities involves the formulation and implementation of energy-saving and carbon reduction policies and technologies in the fields of energy, transportation, industry, construction, agriculture, and life. This needs to be based on the premise of mastering carbon emissions data in various fields and regions. It is necessary to coordinate efforts across the country, focus on key areas, and promote them systematically. We must not go about it aimlessly, treating symptoms rather than the root cause.

From the perspective of system efficiency, through the collection, analysis, and modeling of energy consumption activities and carbon emissions data, combined with AI technologies such as deep learning and large models, the optimization of energy use strategies and process planning in industries such as energy, transportation, construction, and industry can be achieved, so as to achieve energy saving and carbon reduction from a systemic perspective by improving the efficiency of operation and energy use.

The collection and accounting of carbon emissions data at the city boundary also has its own characteristics: in the increasingly open market economy environment, the functional and consumption characteristics of cities determine that cities need to meet the functional needs of goods and services through cross-city border logistics, which leads to the carbon emissions generated by the use of fossil energy, the flow of raw materials and products, and the separation of production and consumption in geography. As a result, a large amount of indirect carbon emissions are hidden in secondary energy use, product and service consumption, and transferred across city boundaries along the supply chain. This greatly affects the systemity and accuracy of city carbon emissions data collection and calculation. These carbon emissions flowing across city boundaries are usually referred to as city carbon footprints. The accuracy of city carbon footprint accounting is also critical in the systematic planning and coordinated promotion of the city's net-zero carbonization roadmap.

To this end, this section will start from the establishment of a city-level carbon emissions data management platform that is measurable, reportable, and verifiable (Monitoring, Reporting, Verification), and build a city carbon data base. By leveraging big data and Internet of Things (IOT) technologies to promote real-time collection, accurate calculation and traceability of carbon emissions data, selecting scientific and reasonable carbon accounting perspectives and carbon emissions collection methods, and accurately calculating the carbon footprints of city's basic carbon emission units and cross-border carbon footprints, it will help to clarify the city's carbon emissions responsibility distribution in the national and even global supply chain. At the same time, with the support of data, the "dual carbon" brain can be built, and AI technology can be used to model emission data, which can help city decision-makers to formulate timely and efficient city carbon emissions management strategies and improve the system efficiency of the operation of all fields in the city.

3.1.1 Building the Carbon Data Base

1. Choose a Scientific and Sustainable Boundary and Perspective for City Carbon Assessment.

The main carbon emission accounting perspectives for cities within their boundaries, according to different management objectives, are as follows:

a. Accounting Perspective Based on Production Within the Regional Scope: Direct carbon emissions generated by all energy and non-energy activities

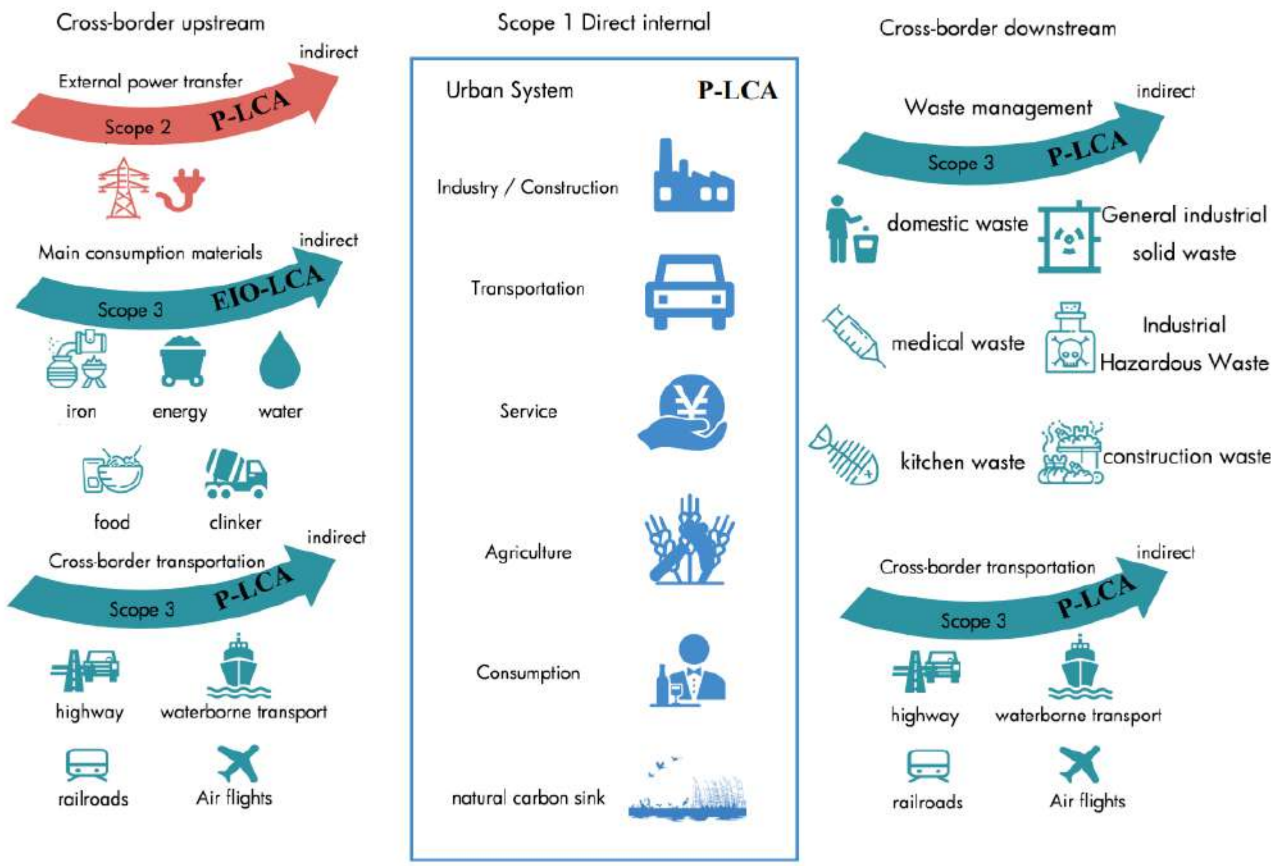


Figure 3-2: Schematic illustration of the perspective of carbon emission accounting at the city boundary

Source: "Carbon Footprint Accounting of Cities from the Perspective of Life Cycle and Suggestions on Paths to Achieve Carbon Neutrality--Taking Shenzhen as an Example".

(chemical processes and animal intestines emmisions, etc.) within the city's geographical administrative boundary. This production-based perspective is difficult to clarify the carbon emissions from secondary energy consumption and Scope3 generated across city boundaries, which is not conducive to the systematic promotion of carbon reduction across the country and even the world.

b. Accounting Perspective Based on the Regional Scope and Supply Chain: In addition to direct emissions within the region, it also includes indirect emissions caused by cross-city boundary activities represented by outsourced electricity, heat, and major industrial raw materials in the upstream supply chain. This perspective considers the carbon emissions generated by secondary energy consumption and major raw materials in the upstream, but the impact of carbon-containing product consumption on the downstream has not yet been taken into account, which is also not conducive to the overall systematic carbon reduction process.

c. Accounting Perspective Based on Final Consumption: All direct and indirect carbon emissions generated in the global value chain driven by final consumption activities within the city boundary (government consumption, household consumption, etc.). This perspective simply considers carbon emissions from a final consumption perspective. This perspective can best reflect the carbon emissions situation on the demand side, and it is also most conducive to reflecting the carbon source's emission intention and carbon reduction responsibility. However, this perspective requires that the carbon footprint of all carbon-containing products and goods in the global scope can be standardized and accurately measured, which is difficult to achieve from the perspective of operability and cost-effectiveness.

d. Based on the Carbon Emission Full Life Cycle Accounting Perspective: i.e., the sum of direct carbon emissions generated by energy and non-energy activities within the city's geographical boundaries and indirect carbon emissions occurring outside the city boundaries, to build a full life cycle carbon emission accounting perspective that covers upstream production inputs, direct use, downstream circulation, disposal, and recycling. This perspective considers both direct carbon emissions and emissions generated by secondary energy consumption, and also considers the carbon footprint of the upstream and downstream circulation of carbon-containing products. It can more comprehensively reflect carbon emission responsibility and willingness from the demand side, while also being both feasible and cost-effective.

Therefore, the carbon emission full life cycle accounting perspective can scientifically and reasonably reflect carbon emission responsibility and willingness from the demand side and the goal of carbon emission system management in the current stage. It also follows the guiding principle of "carbon peak and carbon neutrality" put forward by President Xi Jinping and the overall promotion principle of "four together". However, the accounting also puts forward higher requirements for the collection and circulation of carbon emission data, and it is necessary to build a digital carbon emission collection, accounting and analysis system that matches it.

2. Data Collection and Carbon Emission Accounting Methods Should be Selected According to Different Carbon Sources.

In terms of carbon source identification and data collection, cities should systematically classify their carbon sources according to the requirements of carbon accounting from the consumption perspective. Based on the different types of carbon sources, cities should select and implement carbon emission collection methods and accounting methods that match them.

According to ISO14064, carbon sources of carbon dioxide emissions can be divided into three categories: direct emissions (Scope 1), indirect emissions (Scope 2), and embedded carbon emissions (Scope 3). Therefore, cities need to select appropriate data collection methods to collect relevant data on energy activities, consumption of carbon-containing raw materials, and direct carbon emissions, and then calculate carbon emissions through emission factor method, mass balance method, and actual measurement method.

a. Direct Emissions (Scope 1)

Direct emissions are those that are directly released into the atmosphere from activities such as the combustion of fossil fuels, biomass, or industrial processes. They are essentially from a production perspective. Data collection methods for direct emissions can be further divided into the following types: solid fuel combustion, liquid fuel combustion, industrial process emissions, and Continuous Emission Monitoring System (CEMS).

- Solid Fuel Combustion - Emission Factor Method: To calculate carbon emissions from solid fuel combustion, which is a type of direct emission, automobile scales or belt scales can be used to collect the mass of solid fuel. For example, in the material entry process, electronic automobile scales can be used to weigh the solid fuel transport vehicles entering the site to collect the mass data of the input carbon-containing fuel. Alternatively, before combustion, belt scales can be used to continuously weigh the fuel on the conveyor belt. After collecting the fuel mass, the emission factor method can be used to calculate carbon emissions using the factors defined in energy carbon emission factor standards such as the "General Principles for Comprehensive Energy Consumption Calculation" (GB/T 2589-2020).

- Gas and Liquid Fuel Combustion - Emission Fac-

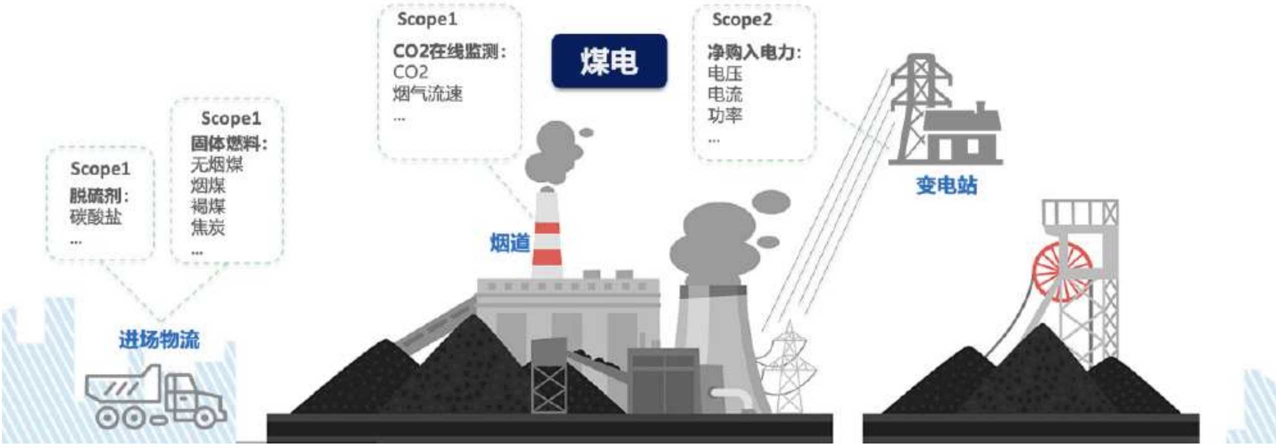


Figure 3-3: diagram of carbon emission monitoring in the coal power (energy) sector Source: draw by author

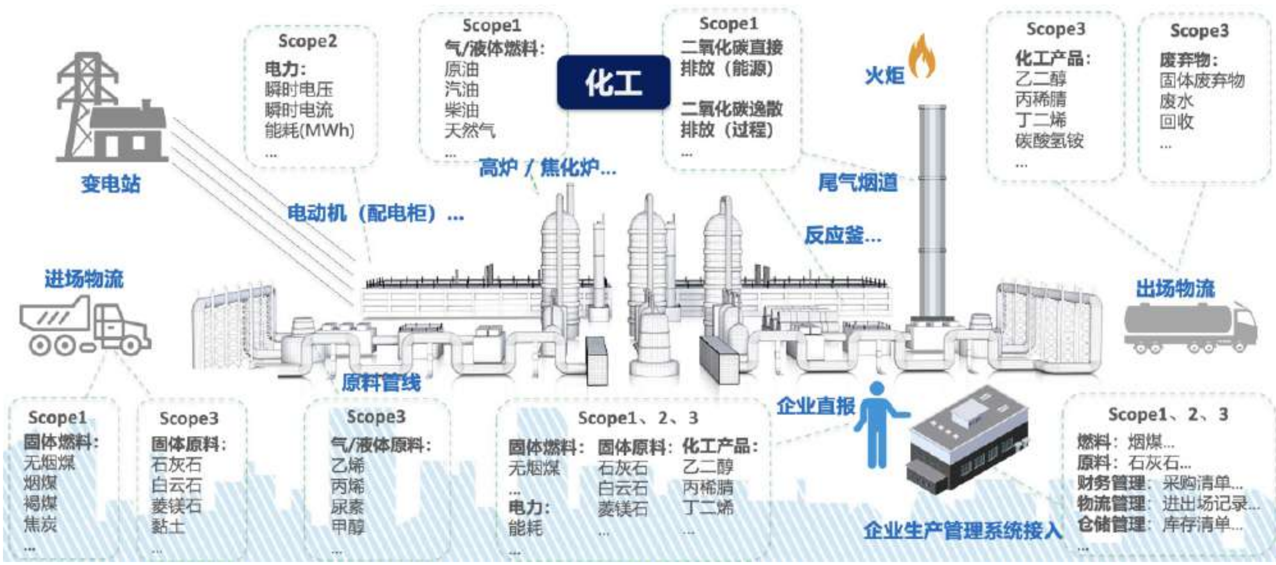


Figure 3-4:diagram of carbon emission monitoring in the chemical (heavy industry) sector Source: draw by author

Figure 3-5:diagram for monitoring carbon emissions from restaurants

Source: draw by author

Figure 3-6:diagram for monitoring household (domestic) carbon emissions

Source: draw by author

Figure 3-7:diagram of carbon emission monitoring for intra-city transportation Source: draw by author

tor method: For scenarios using gas and liquid fuels, contact or non-contact gas and liquid flow meters can be installed on the outside of the pipeline. Using ultrasonic, vortex, electromagnetic, and turbine principles, the volume flow rate or mass flow rate of gas, steam, or liquid can be measured in real time. Then, the emission factor method can be used to calculate carbon emissions.

- **Industrial Process Emissions - Mass Balance Method:** For fugitive emissions generated by non-combustion industrial processes (such as decarbonization and desulfurization), the mass of raw materials and products can be obtained using the above-mentioned belt scales, flow meters, and other solid, gaseous, and liquid material mass acquisition methods. Using the principle of mass conservation (carbon emissions are calculated by subtracting the carbon output of non-carbon dioxide from the carbon content of the input), the carbon dioxide emissions of the non-combustion industrial process can be obtained.

- **Continuous Emission Monitoring System (CEMS) - Actual Measurement Method:** For direct emissions, CEMS can also be used to directly monitor the carbon dioxide emissions in the device exhaust gas. This method mainly measures the smoke flow rate, carbon dioxide concentration, and humidity in the flue gas to calculate the carbon dioxide emission rate per unit time.

- **Carbon Satellite Inversion - Actual Measurement Method:** For direct emissions over a wider area, carbon satellite high-resolution remote sensing technology can be used to quantitatively analyze the carbon dioxide content in the atmosphere of a specific area. Through the form of sky-to-ground inversion, the carbon dioxide direct emissions data for a specific area can be realized.

b. Indirect Emissions (Scope 2)

Indirect emissions are those that are implicitly emitted as a result of using, consuming purchased electricity, heat, and steam. Indirect carbon emissions do not occur within the boundary of the carbon-using entity's facilities, but are indirectly caused by the carbon emissions generated in the process of energy production due to the demand of the using entity. They are essentially a consumption perspective of carbon emissions.

- **Electricity Carbon Emissions - Emission Factor Method:** Electricity is an important secondary energy that permeates all aspects of the economy and society. From a consumption perspective, the proportion of green electricity with mixed zero emissions on the load side will gradually increase. Therefore, the accounting of electricity carbon emissions will tend to shift to the supply side (fossil fuel power generation enterprises). Electricity consumption can be calculated by connecting current and voltage sensors to the power circuit to calculate the power consumption of the load in unit time, or by sharing data such as invoices, consumption records, and payment settlement sheets from the energy consumption unit information system. The carbon emissions can be calculated by using the electricity carbon emission factors for various regions in the "Enterprise Greenhouse Gas Emissions Accounting Methods and Reporting Guidelines - Power Facilities" issued by the Climate Change Department of the Ministry of Ecology and Environment of China.

- **Heat and Steam Carbon Emissions - Emission Factor Method:** For purchased heat, steam, and other secondary energy, temperature and pressure sensors can be used to collect temperature and pressure data for steam and hot water. The heat value of hot water and steam can be calculated by calculating the heat value and then converting the standard coal consumption according to the heat value. Finally, the carbon emissions of heat and steam can be calculated using the emission factor defined in GB/T 2589-2020.

c. Embodied carbon (Scope 3)

Embodied carbon refers to the total amount of carbon dioxide emitted directly and indirectly during the entire production process, from the extraction of raw materials to the production of final products. The commonly used methods for embodied carbon accounting are input-output analysis and life cycle assessment (LCA).

- **Input - Output Analysis:** Input-output analysis is an economic analysis method that studies and analyzes the quantitative dependence relationship between product production and consumption in various departments of the national economy. It mainly establishes a simplified and systematic activity model of the comprehensive economic activities of a country or region by representing the situation of various economic activities in a specially designed input-output table.

In the analysis and calculation of embodied carbon, input-output analysis can be used to analyze the input of carbon-containing energy and the output of carbon-containing products, so as to track the direct and indirect energy use of products produced in each administrative region and the carbon dioxide emissions generated.

Input-output analysis is a macro method for regional carbon emission accounting. The input-output table released by the official statistical agencies in China covers provincial administrative units. Therefore, using input-output analysis to calculate embodied carbon will not be able to compare carbon emission accounting in areas smaller than provincial administrative units. This method has significant limitations for the analysis of embodied carbon at the micro level, such as cities and even enterprises.

- **Life Cycle Assessment:** Life cycle assessment (LCA) is a method for calculating the amount of carbon dioxide emitted during the entire life cycle of a product, including the carbon dioxide emissions generated in all stages of the product life cycle, from the acquisition of raw materials to production, transportation, use, maintenance, recycling, and disposal. This method is a product-based embodied carbon calculation method.

Life cycle assessment is a micro method that can analyze the embodied carbon of micro carbon sources such as cities, enterprises, and products. It can provide more specific information for decision-makers. However, this method requires strict data integrity for product raw materials, fuels, and production processes.

In the context of the increasingly developed informatization level of industrial production enterprises and the increasingly complete retention of production process data by enterprises, LCA will occupy the mainstream position in the calculation of embodied carbon.

3. Building a Trustworthy, Reliable, and Traceable Carbon Data Chain

Due to the complexity of carbon emission data collection, especially the flow relationship of embedded carbon emissions in energy, raw materials, intermediate products, and end products, using blockchain technology to construct a traceable carbon data chain can ensure that carbon emission data has traceability and unalterable data security features during the process of collection and flow. It can provide corresponding data security features in each link of carbon data MRV:

a. In the Monitoring Stage: the carbon data chain can provide data distributed ledger evidence at the source of carbon emission data collection, trace and source industrial process carbon emissions, and calculate product carbon footprints;

b. In the Reporting Stage: blockchain and privacy computing technology are combined to verify carbon emission data on the chain and ensure the authenticity of the reporting data;

c. In the Verification Stage: the anti-tampering feature of the carbon data chain is used to reduce the difficulty of verification.

4. Establish carbon source accounts

To make the carbon emissions data transparent and to clarify the low-carbon contribution and carbon reduction responsibility of various social entities, we will establish unified carbon accounts for carbon sources such as enterprises and individuals/households. These accounts will be used as tools for carbon emissions assessment and management. The carbon source accounts will integrate with carbon finance and carbon trading markets to play a regulatory role of the market and increase the subjective driving force of carbon reduction for various carbon sources to promote the realization of the dual carbon goals.

a. Enterprise Carbon Accounts: Establish carbon emission accounts for corporate legal entities. The carbon account-centered assessment system for regulated enterprises will be established to optimize the operating mechanism, and promote the establishment of an enterprise carbon emission accounting and evaluation system across society. The establishment of enterprise carbon account and carbon credit reporting standards, will help to strengthen carbon emission information sharing and data docking, and encourage financial institutions and local financial institutions.

b. Individual / Household Carbon Accounts: Establish carbon emission accounts for individuals based on the quantitative evaluation of carbon emissions from activities such housing, and transportation in the lives of individuals and households, as well as green and low-carbon behaviors. Link the level of individual carbon emission accounts to various life application scenarios, which will help to enhance public awareness of green and low-carbon, advocate for low-carbon living, and build a net-zero carbon society.

Figure 3-8:"dual carbon" brain Source: ISSTECH

3.1.2 Building City "Dual Carbon" Brain

Under the effective support of the city-level "dual carbon" data platform, leveraging artificial intelligence technology, we will build "dual carbon" application support capabilities for zero-carbon city planning, carbon target assessment, and energy, buildings, industry, transportation, agriculture, and living, which are key emission sectors. This will build a city-level "dual carbon" brain.

The "dual carbon" brain is a group of AI models with multimodal large models at the core. Through multimodal large models, it provides multimodal input and output capabilities, such as time series, text, speech, and images. It also connects downstream "dual carbon" application small models (such as CGE, LEAP, and LMDI) to build a digital "dual carbon" application support model group. This will achieve macro-coordination and micro-efficiency optimization of the city's net-zero carbonization process, enhance the city's resilience to climate change, and empower the city's net-zero carbon roadmap with digital technology.

a. Economic-Energy-Environmental Balance Model: Economic-energy-environmental balance is an important balance process for the high-quality development of net-zero carbon cities. By modeling the complex energy-environment-economic system of cities using a Computable General Equilibrium (CGE) model as the core, we can use this model to comprehensively analyze a series of key issues in the green and low-carbon transition in China, regions, and the world.

b. Carbon Peak Time Prediction: To predict the carbon peak time, we establish the LEAP (Long Range Energy Alternatives Planning System) model. Based on social macro-economic data, combined with micro-data such as enterprise energy consumption, carbon emissions, and output value, we use LSTM (Long-Short Term Memory) and other time series data prediction algorithms to dynamically predict and simulate the carbon emission trends of the whole country and each region during the data period, and to predict and simulate the carbon peak time and peak carbon emissions.

c. IPCC Scenario Analysis and Target Decomposition: Scenario analysis and target decomposition are conducted by using IPCC scenario analysis models and energy-saving and emission reduction assumptions, such as: simulation analysis under the combined scenarios of the five SSPs (Shared Socioeconomic Pathways) and four RCPs (Representative Concentration Pathways) defined by IPCC (Intergovernmental Panel on Climate Change) AR6, in different time periods, under the influence of factors such as temperature change, carbon emissions, and social and economic development. Starting from the implementation roadmap of net zero carbonization, the overall goal of IPCC scenarios is decomposed into different jurisdictional regions and emission reduction fields, to achieve the implementation and evaluation of emission reduction scenarios.

d. Economic Impact Analysis Model of Carbon Emission Limits: Based on the CGE model constructed by the "dual carbon" brain, by analyzing how different regions achieve carbon reduction targets and the cost impact of achieving them in terms of energy supply (such as electricity and renewable energy supply) and energy consumption (such as residential life and key industries), we can obtain quantitative predictions and simulations of the economic impact of carbon reduction, to support the formulation of carbon reduction targets and strategies.

e. Multi-objective Energy Strategy Optimization: Improving the economic efficiency of energy system operation, reducing pollution emissions, and improving energy utilization efficiency are important goals for the development of net-zero carbon city energy systems. In the actual planning and operation of energy systems, due to the complex correlation between different objectives (such as energy economic efficiency, carbon emissions, energy utilization efficiency, and user satisfaction), it will be difficult to obtain the global optimal solution when the number of energy objective functions is more than three. By constructing a multi-objective renewable energy development optimization model, considering the multi-objective requirements of energy economic efficiency, carbon emissions, energy efficiency, and user satisfaction, a multi-objective optimization model is established. By solving this strategy model, the energy planning can be both globally optimal and robust.

f. Urban Traffic Efficiency Optimization: Urban traffic efficiency is closely related to traffic carbon emissions. Urban traffic has the following characteristics: complex road network, large redundant routes, large fluctuations in traffic flow, and significant tidal phenomena. Traffic optimization models such as dynamic path optimization, intelligent traffic lights, and dynamic lane setting can be used to improve the efficiency of the urban traffic system. Dynamic path optimization divides the road network into a series of areas and dynamically optimizes the traffic flow path through the ant colony algorithm to achieve the balance of traffic flow and reduce the congestion rate; traffic lights dynamically set the bidirectional timing of traffic lights, green waves, and other scenarios through traffic data and model analysis to improve the efficiency of intersection traffic; dynamic lane setting dynamically adjusts the lane attributes according to the type, direction, and number of traffic vehicles to optimize the traffic flow in each lane, improve the system's throughput efficiency, and reduce the overall carbon emissions of traffic.

3.1.3 Promoting Green Data Centers

In the context of the rapid development of artificial intelligence technologies such as AIGC large models, the energy demand for supporting urban intelligent computing infrastructure, including the "dual carbon" brain, is also becoming increasingly strong, and the power consumption of data centers is also increasing rapidly. According to data from the China Academy of Information and Communications Technology, China's national data center total power consumption reached 216.6 billion kilowatt-hours in 2021, and carbon emissions reached 135 million tons, accounting for about 1.14% of China's total carbon dioxide emissions. It has become one of the important influencing factors for the national "carbon peak and carbon neutrality" goal.

The "Uptime Global Data Center Survey 2021" pointed out that since 2014, the PUE of global large data centers has remained at the level of 1.6 for seven consecutive years, and the energy efficiency utilization rate of data centers is low and needs to be improved. To promote the sustainable development of the data center industry, multiple countries and international organizations have issued data center-related policies, such as the US government through the DCOI data center optimization initiative, requiring new data centers to have a PUE of less than 1.4 and old data centers to have a PUE of less than 1.5. European data center operators and industry associations announced in the " Climate Neutral Data Centre Pact"(CNDCP) that they will achieve carbon neutrality in data centers by 2030. China has issued the "Implementation Plan for the Integrated Innovation System of National Integrated Data Centers" to promote the construction of a national integrated data center, launch the "East-West Computing" project, promote the green and sustainable development of data centers, accelerate the research and application of energy-saving and low-carbon technologies, and require that by 2025, the PUE of new large data centers will be less than 1.3. Under the driving force of the carbon neutrality target, the data center industry will undergo profound changes, and the low-carbonization of data centers will become an inevitable trend. The large-scale application of clean energy, the development of stacking light and storage, and waste heat recovery will effectively help data centers achieve sustainable development.

a. AI Enabled Operation Efficiency

- **Efficient Cooling:** In addition to IT equipment, the power consumption of data center cooling systems accounts for a large proportion. Traditional cooling group control systems have challenges such as fewer than 10 collected parameters, fewer than 3 adjustable parameters, slow and inaccurate adjustment speed, each optimization takes 2 hours, and the adjustment effect lasts for a short time. At the same time, it mainly relies on manual tuning, which is heavily dependent on expert experience and requires very high skills. For increasingly complex cooling systems, manual adjustment based on expert experience cannot be adjusted in real time according to environmental parameters and load rates. Moreover, in order to ensure system reliability, cooling demand is often amplified layer by layer, resulting in energy waste.

Green data center energy efficiency optimization uses AI technology to dynamically model and establish machine learning models between energy consumption and IT equipment load, climate conditions, equipment operation, and other adjustable parameters. On the basis of ensuring the reliability of equipment and systems, it can diagnose the energy consumption of each subsystem in real time, and automatically and accurately infer and configure the optimal control logic for the data center. Through deep neural network training, a PUE prediction model is obtained, and finally the most suitable instruction is output. Within 1 minute, the best cooling strategy is inferred from the original combination of 1.4 million environmental parameters, and the execution is issued and the effect is fed back to achieve the optimal energy efficiency of the data center.

- **Efficient IT Equipment Operation:** In data center operations, with the changes in business, the large number of equipment on and off shelves brings great challenges to the management of data center cabinet space resources. Data centers often have some cabinets that are not fully utilized or even idle, while some cabinets have high loads. How to more efficiently manage data center resources and maximize their utilization is a problem that green data centers need to consider.

AI-based resource optimization technology manages data center assets throughout their lifecycle. It establishes a management model and analysis platform with equipment management as the core. Through AI simulation of equipment status and AI business forecasting, it automatically inventories the status of data center assets. Based on the precise positioning of asset U positions, it comprehensively analyzes factors such as available cabinet space, available power, available cooling, and available network (SPCN: Space, Power, Cooling, Network). Intelligently recommend the best cabinet position for equipment to be placed, realize thevisibility and controllability of data center resources, avoid capacity stranded, realize the maximum utilization of data center resources, and improve resource utilization

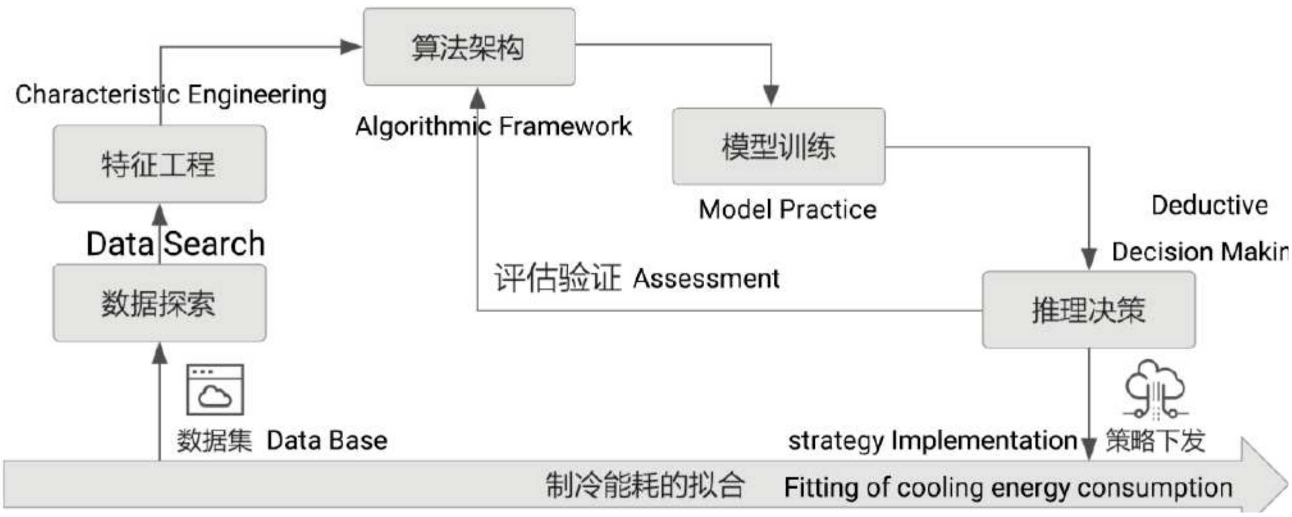


Figure 3-9:High efficiency refrigeration control strategy Source: Next Generation Data Center White Paper, Huawei

and operational benefits.

- **Efficient Energy Utilization:** As the input and use of data center energy becomes increasingly diversified, AI technology can be used to realize the flexible optimization scheduling of various energy sources. It can achieve on-demand calling in terms of green power direct supply, photovoltaic stacking, and energy storage peak shaving, reducing manual calculation and operation, and maximizing the value of resources.

b. Resource Recycling

Data centers are major energy consumers and also major heat producers. The electricity they consume is eventually converted into heat and released into the air, which is not effectively utilized. It also forms a heat island around the data center, affecting the cooling PUE. Heat recovery is an important technology in the low-carbon era and is also one of the important characteristics of green centers.

The Climate Neutral Data Centre Pact(CNDCP) clearly states that heat recovery is one of the five key measures to achieve carbon neutrality by 2030. The European Sustainable Infrastructure Alliance (SDIA) has included heat recovery in its roadmap, with a data center heat recovery rate of over 60%.
Through heat recovery, the recovered heat can be used for:

- **Self-use by data centers, such as for living hot water in office areas and heating of oil machine rooms.**
- **Supporting industries around data centers, such as breeding or heating of commercial complexes.**
- **Integration into municipal heat pipelines.**

In addition to the heat recovery of data centers, it is also necessary to pay attention to the recyclability of the materials of data center equipment and facilities themselves. In the future, more and more regions will promote the use of new prefabricated green buildings and green building materials with a material recovery rate of over 80%. By using lead-free and halogen-free green recyclable new materials to replace traditional lead-containing harmful substances at the levels of components, boards, components, and accessories, a higher recycling rate can be achieved, promoting data centers to low-carbon, circular, and sustainable development.

3.2 Formulating Carbon Strategy

Climate change and environmental problems are not only caused by pollution emissions, but also by energy, industrial structure, consumption patterns, and macro and micro-level decision-making. They have a profound impact on the social economy.

How to achieve the "dual carbon" goal as scheduled while maintaining stable economic development has become a green development requirement for countries around the world, including China. This requires countries to balance the relationship between economic development and the use of traditional fossil fuels while saving energy and reducing carbon emissions, ensuring that the future net-zero carbon development roadmap for cities is of high quality, green, circular, and sustainable.

Therefore, cities need to establish a set of systematic strategies and policies to address climate change, seeking a dynamic balance between energy, environment, economy, and society, and promote long-term sustainable social development. Based on digital technology, building a city carbon management positive feedback closed-loop management mechanism and model with the goal of coordinated development of energy, industry, development model, pollution control, resident health protection, and social livelihood, is of great significance to the decision-making support for the net-zero carbonization of cities.

At the same time, China has a vast territory, a complete industrial chain with a wide distribution, and significant differences in industrial structure and natural resource endowments in different regions. This determines that the action plans of different cities in promoting the "dual carbon" goal should be differentiated and precise. Therefore, in the development policies of "carbon neutrality", we should not adopt a "one-size-fits-all" or "herd" approach. The realization of the "carbon neutrality" goal should be coordinated nationwide to form a systematic carbon reduction force. Finally, in order to address the complexity and systematicity of the "carbon peak and carbon neutrality" goal, we need to incorporate a holistic perspective throughout the "carbon neutrality" process, and pay attention to handling the four relationships between development and reduction, overall and local, long-term and short-term, and government and market.

3.2.1 Building a Carbon Management Feedback Loop

In urban system administrative management, the direction of administrative management is top-down, while there is a lack of upward channels and mechanisms from bottom to top. The process of carbon emission management is similar to this. In practice, in order to optimize the operation of the urban system, it is necessary to establish a feedback channel based on a digital system, form a feedback mechanism from the grassroots to the upper level, and realize the impact and role of the end on the beginning, so as to build a dynamic equilibrium state of carbon neutrality, and thus dynamically maintain the carbon neutrality state of the city.

Based on the carbon data base and the digital collection and analysis capabilities of the "dual carbon" brain, and the corresponding MRV(Monitoring, Reporting, Verfication, mechanism, a city's effective and reliable carbon emission reduction strategy implementation effect feedback channel is constructed. Through the data and feedback of energy conservation and emission reduction effects, the derived carbon market, carbon finance and other market-oriented tools are promoted, and the city system is driven to the direction of overall energy conservation and emission reduction benefits growth (systemic energy conservation and emission reduction). Therefore, by building a three-step carbon management positive loop of mastering carbon data-formulating carbon strategies-smart carbon actions, not only the benefits of the entire system's end are compensated, but also the benefits of the entire system are increased. With the iterative cycle of the feedback loop, the driving force for energy conservation and emission reduction in the urban system will also be improved, and the benefits of system energy conservation and emission reduction will gradually increase, which will form a self-incentive virtuous cycle of urban energy conservation and emission reduction.

a. Mastering Carbon Data: During the implementation of "dual carbon" policies and strategies, it is necessary to monitor the implementation effects. The unified and reliable urban carbon data base built by this construction will be used to collect and summarize the data, establish a city carbon emission accounting mechanism, and realize the fine-grained and high-frequency data collection and effect monitoring of regional carbon emission reduction effects, forming a carbon management data loop.

b. Formulating Carbon Strategies: Use data to support the planning and formulation of energy conservation and emission reduction, new energy substitution and carbon fixation strategies in key carbon emission areas. Decision-makers use data to drive the planning, formulation and implementation of new policies, and promote the scientific and coordinated development of "dual carbon" across the country.

c. Smart Carbon Actions: Under the guidance of scientific carbon strategies, governments and enterprises at all levels will formulate corresponding "timelines, roadmaps, and construction plans" to implement effective energy conservation and emission reduction actions in the fields of energy, buildings, and transportation, and solidly promote the realization of the "dual carbon" goal.

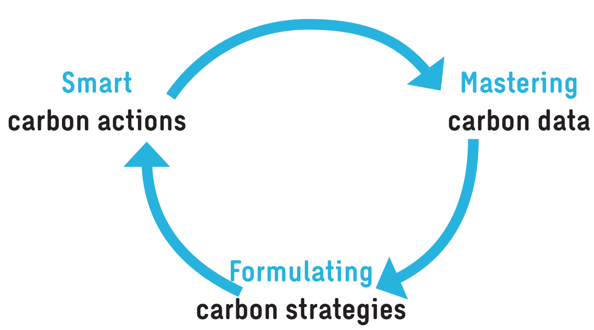


Figure 3-10:Building a carbon management feedback loop

Source: draw by author

3.2.2 Making Strategy Base on Local Conditions

From a global perspective, different countries and regions have significant differences in terms of natural resource endowment, production and living patterns, industrial structure, and industrialization process. Therefore, the path to achieving net-zero carbonization will not be the same, and the formulation of relevant strategies should also be tailored to local conditions, such as:

- Different Energy Resource Endowments: Countries such as Russia, the United States, and Canada have abundant fossil energy resources, while the energy supply of countries such as the United Kingdom, France, Germany, and Japan is highly dependent on the international market. Since the 1970s, resource-saving countries have focused on green transformation and significantly improved energy efficiency to meet the needs of energy security and environmental protection.

- Different Lifestyles: The United States has 5% of the world's population, but consumes 25% of the world's oil. The American lifestyle leads to significantly higher household carbon emissions than the world average. For example, American households mainly use dryers to dry clothes after washing (which consumes electricity), and the average household has more than one car (which consumes oil).

- Different Levels of Renewable Energy Utilization: European countries generally attach great importance to the development of renewable energy, such as France's nuclear power, Germany's photovoltaics, Norway's hydropower, and Denmark's wind power. By continuously increasing the proportion of renewable energy, they have achieved faster decoupling of energy use from carbon emissions.

China has a wide range of natural resources and industrial structures. These differences cannot be ignored. The expectation that different regions can achieve the "dual carbon" goal in a "step-by-step" manner is unrealistic and irresponsible. Therefore, the action plans for the "dual carbon" goal should be differentiated and personalized, and policies should not be "one size fits all" or "copycats." The realization of the "dual carbon" goal should be coordinated across the country to form a systematic force to reduce carbon emissions.

a. Industry Structure: The "dual carbon" goal has put forward an urgent requirement for the optimization and upgrading of industrial structure. According to the calculation data of the Resource Conservation and Environmental Protection Bureau of the National Development and Reform Commission of China(NDRC), the overall contribution of industrial structure adjustment to carbon reduction is over 50%.

The focus of optimizing the tertiary, secondary, and primary industries is to increase the proportion of the tertiary industry, while gradually reducing the proportion of the secondary industry. The focus of adjusting the internal structure of the secondary industry is to strictly control the growth rate of high-energy-consuming and high-emission industries, while increasing the proportion of low-energy-consuming and low-emission industries. At the same time, the focus at the product level should be on increasing product added value, thereby reducing the unit GDP energy consumption and carbon emission intensity.

From the perspective of the specific regional distribution of industrial structure differences, most provinces in eastern China have entered the late stage of industrialization, and the primary and tertiary industries are the main industries in the western region. Moreover, the western region is rich in renewable energy such as solar and wind energy. Therefore, the eastern and western regions are easier or have more conditions to achieve the green transformation of economic development. The central region, especially provinces such as Inner Mongolia, Shaanxi, and Hebei, are rich in coal resources and are dominated by heavy industries that use fossil fuels as the main energy. The difficulty of industrial structure adjustment and green transformation is relatively large.

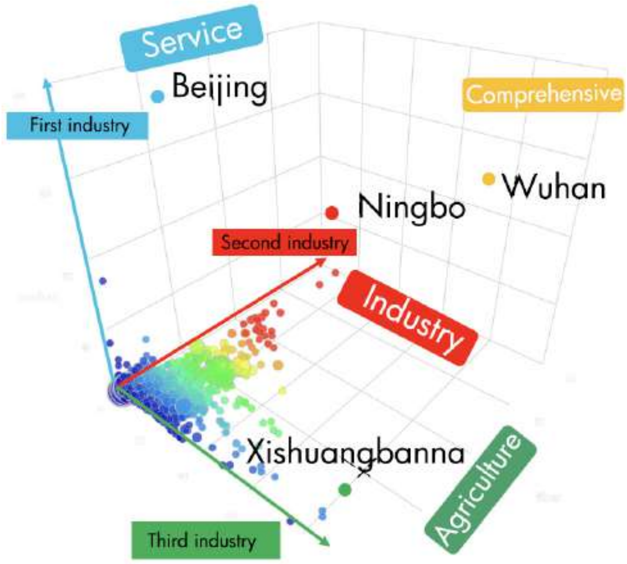


Figure 3-11:Analysis of Urban Categorical Approach
Source: draw by author

Therefore, it is necessary to further subdivide cities according to economic indicators such as the tertiary, secondary, and primary industries, and data such as energy and carbon emissions. This will allow for the targeted and accurate formulation of energy conservation and emission reduction strategies, and the implementation of personalized net-zero carbon roadmaps.

b. Resource Endowment: Renewable energy substitution for fossil energy is a key part of "dual carbon" development. Zero-carbon renewable energy such as solar, wind, and water energy is closely related to the resource endowment of the region. Therefore, when formulating a renewable energy development strategy, each region should fully consider and tap into the local natural resource endowment, first establish and then break through, and implement renewable energy substitution strategies in a targeted manner under the premise of ensuring energy security.

The development and resource distribution of China's new energy are as follows:

- Solar Energy: The distribution characteristics of China's total solar radiation resources are as follows: the west is higher than the east, the plateau is higher than the plain, the inland is higher than the coast, and the dry area is higher than the humid area. Ningxia, Gansu, southeastern Xinjiang, western Qinghai, and western Tibet are the regions with the richest solar energy resources in China, with annual sunshine hours reaching 3200-3300.

- **Wind Energy:** According to the fourth wind energy resources survey data of the China Meteorological Administration, the potential development of wind energy resources on land at an altitude of 50 meters above sea level in China is 23.8 billion kilowatts, and the potential development of wind energy resources in the near sea area with a water depth of 5-25 meters is about 2 billion kilowatts. The potential wind energy resources in the "Three North" regions (North China, Northeast China, and Northwest China) and the southeastern coastal areas and offshore islands are relatively concentrated, with a development volume accounting for about 80% of the country.

- **Water Energy:** China's water energy resources are unevenly distributed in space and time, and they are not coordinated with the energy-consuming regions. From the spatial distribution, three-quarters of the total water energy resources in the country are concentrated in the relatively backward and inconvenient economic western region, of which Yunnan, Sichuan, and Tibet provinces (autonomous regions) account for 60%. The second is the middle and northwest regions, accounting for 15.5% and 9.9% respectively. The eastern region of China, where the economy is developed and the load is concentrated, including 13 provinces (municipalities directly under the central government) such as Liaoning, Jilin, Heilongjiang, Beijing, Tianjin, Hebei, Shandong, Jiangsu, Zhejiang, Anhui, Shanghai, Guangdong, and Fujian, accounts for only about 7%, and the development level has reached a relatively high level.

3.2.3 Adhering to a Holistic View and Handling the "Four Relationships"

To address the complexity and systemic nature of the "carbon peak and carbon neutrality" goals, Chinese President Xi Jinping emphasized that it is necessary to incorporate a systems perspective throughout the entire "dual carbon" process, and pay attention to handling the four relationships of development and reduction, overall and local, long-term and short-term, and government and market.

a. The Relationship between Development and Reduction. Xi Jinping pointed out that "reduction is not reducing productivity, nor is it not emitting, but to follow the path of ecological priority and green low-carbon development, and to achieve greater development in economic development." Therefore, it is necessary to break the misconception of extensive development, and accurately identify and eliminate backward production capacity to upgrade "stock"; also vigorously develop emerging green and low-carbon industries to improve "added value"; at the same time, accelerate the transformation and promotion of scientific and technological achievements to use "variables." Through digital technology innovation, coordinated planning can ensure energy security, supply chain security, and food security while reducing carbon emissions, and ensure high-quality economic and social development in the process of cities moving towards net zero carbon.

b. The Relationship between Overall and Local. Xi Jinping also pointed out that "it is necessary to strengthen the awareness of a national chess game, strengthen the coordination of policies and measures, and ensure synergy; it is also necessary to fully consider the objective reality of regional resource distribution and industrial division of labor, and study and determine the direction of industrial structure adjustment and "dual carbon" action plans in each region, and not to implement "one size fits all" or "one size fits all." China's regions have significant differences in resource endowment, economic development stage, carbon emission status, and reduction potential. Through digital technology, on the basis of fully mastering local carbon data, it is necessary to scientifically set "dual carbon" goals and corresponding energy saving and emission reduction strategies that are suitable for regional characteristics to effectively promote "dual carbon" actions. Therefore, all regions and departments should both stand on the basis of reality and make specific implementation plans for carbon peak and carbon neutrality in accordance with local conditions, to ensure that "dual carbon" work is in line with local reality; they should also consciously benchmark against the top-level design of the Party Central Committee to ensure that the "dual carbon" decisions and deployments of higher-level departments are not biased, flexible, or distorted, and that overall and local forces are combined and promoted in coordination.

c. The Relationship between Long-term Goals and Short-term Goals. In setting carbon reduction targets, it is necessary to be based on data, and to both lay out a good plan for the "long-term goal" and make good progress on the "short-term goal" to form a scientific and effective carbon reduction target, and not to be divorced from reality or be ambitious. That is, it is necessary to base itself on the actual work at present, step by step, starting from solving the most outstanding problems at present, focusing on winning the "tough battle" of energy conservation and emission reduction, completing phased tasks, and accumulating small victories into big victories; it is also necessary to look to the long-term, comprehensively analyze, grasp the rhythm and intensity of reduction and carbon reduction, and fight the "long-term war" tirelessly to achieve the long-term goals of "dual carbon" work.

d. The Relationship between Government and Market. It is necessary to strengthen carbon emissions regulation and stimulate market vitality. Xi Jinping pointed out that "it is necessary to adhere to two-pronged efforts, promote the better integration of effective government and effective market, and establish a sound incentive and constraint mechanism for 'dual carbon' work." It is necessary to strengthen the party's leadership in "dual carbon" work, and give full play to the regulatory and regulatory role of the government in market construction. With the modernization of governance system and governance capacity, capital is regulated and guided to focus on green economy, circular economy, and low-carbon economy, to promote "dual carbon" work to achieve high-quality development, that is, through the collection, accounting, and auditing of carbon data, to ensure the authenticity and effectiveness of carbon emissions data management throughout the process; through market-based mechanisms such as carbon trading market, carbon finance, and carbon tax, the decisive role of the "invisible hand" in resource optimization allocation is played, and a sound ecological protection compensation mechanism that can reflect the value of carbon sinks is established, attracting social capital to participate in it, and giving full play to its role as an important production factor, and maximizing the vitality of market entities.

3.3 Smart Carbon Actions

According to the China Carbon Emissions Database, the carbon emissions from energy, construction, and transportation sectors account for more than 50% of China's total carbon emissions. If the carbon emissions from the industrial sector that can be transferred outside the city boundaries through industrial raw materials and product flows are not counted, the percentage of carbon emissions from these three sectors will be as high as 90%. Therefore, smart carbon actions in the energy, construction, and transportation sectors empowered by digital technologies, which are essential to achieving the city's carbon reduction, new energy substitution, and carbon fixation goals, are an important part of the city's net-zero carbon roadmap.

3.3.1 Energy

The National Development and Reform Commission (NDRC) and the National Energy Administration (NEA) of China jointly issued the "Implementation Opinions on Promoting the Construction of Multi-Energy Complementary Integrated Optimization Demonstration Projects" (No. 1430 of the NDRC and the NEA) on July 4, 2016. The purpose of the document is to "improve energy system efficiency, increase effective supply, meet reasonable demand, drive effective investment, and promote economic stability." The purpose of promoting multi-energy complementarity is to achieve "integrated optimization" by using different energy technologies to complement each other's shortcomings, fully integrating

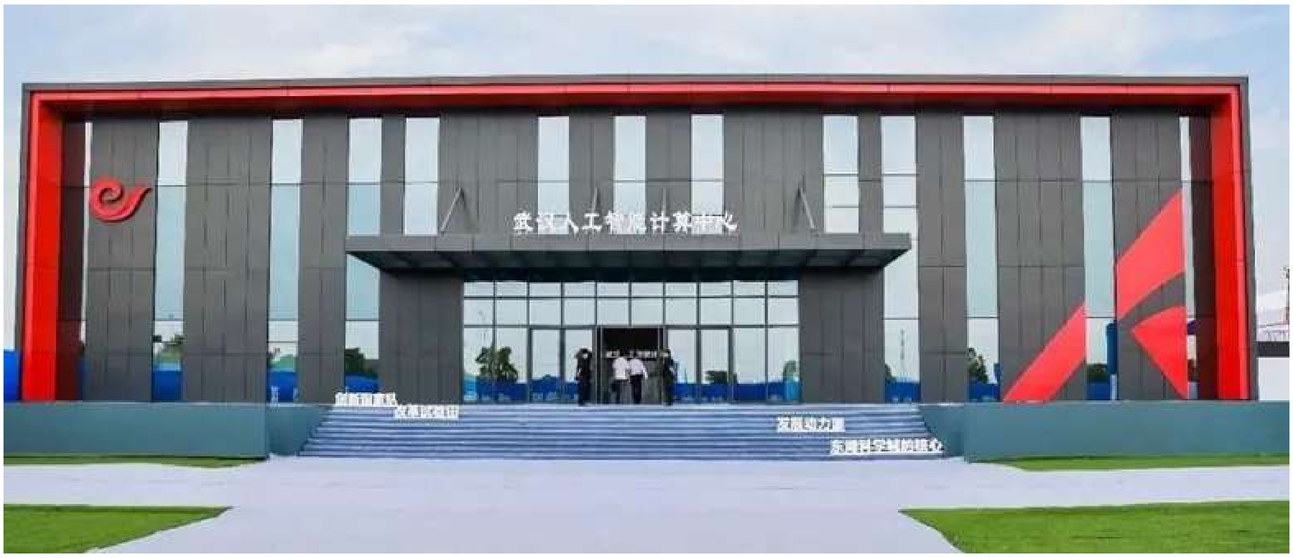


Figure 3-12:Wuhan AI Computing Centre Source: Next Generation Data Center White Paper, Huawei

and utilizing intermittent renewable energy, and reducing end-use energy consumption.

The core logic of energy efficiency optimization is to deeply integrate digital intelligence (bits) and energy technology (watts) through digital energy technology, realize the interaction of information flow and energy flow, and promote the high-density integration and efficient operation of energy products through the digitalization, networking, and intelligence of energy conversion, storage, and control.

Energy efficiency optimization can be further divided into the following methods:

a. Supply-side Optimization: Energy supply-side optimization refers to "the promotion of the construction and operation of multi-energy complementary systems of wind, solar, water, fire, and storage, by taking advantage of the combination of resources such as wind energy, solar energy, hydropower, coal, and natural gas in large integrated energy bases." This is to optimize the efficiency, stability, and economic viability of the energy supply side.

The National Energy Administration of China has promoted the construction of "Wind Power Three Gorges" and "Solar Power Three Gorges" with a capacity of 10 million kilowatts. The State Grid Corporation of China has built ultra-high voltage transmission lines to transmit these ultra-large-scale renewable energy electricity to the economically developed eastern regions. However, the unstable renewable electricity is sometimes available and sometimes not, making it difficult to maintain the voltage stability of the ultra-high voltage transmission lines. To address this contradiction, large-scale coal-fired power clusters are to be built in Xinjiang and other regions in northwest China to develop "wind-fire bundling" or "wind-solar-fire bundling" models. This is a typical case of supply-side optimization of multi-energy complementarity on the supply side.

b. Near-demand Side Optimization: Near-demand side optimization refers to "the promotion of the construction and operation of multi-energy complementary systems that meet the needs of end-users for electricity, heat, cold, and gas. This is achieved through the integrated development of traditional and renewable energy sources, the optimization of the layout of integrated energy supply infrastructure, and the use of natural gas trigeneration, distributed renewable energy, and smart micro-grids to achieve coordinated energy supply and comprehensive energy cascade utilization."The focus of near-demand side optimization is still on improving the efficiency of energy conversion in the energy system on the supply side (including the energy transmission network), rather than starting with helping users to "reduce energy consumption, save money, and save energy."

The State Grid Corporation of China has also begun to explore a Chinese version of the "three-in-one" near-demand side multi-energy complementarity model. Through the configuration of energy storage batteries and smart bidirectional charging piles for some users with rooftop distributed photovoltaics, bidirectional charging piles with the functions of charging and feeding electricity to users or the grid are used to make electric vehicles become mobile energy storage sources. In necessary cases, electric vehicles can provide electricity to the grid in reverse, becoming an important part of the demand side multi-energy complementarity system. All data will be uploaded to the cloud via the internet, and the big data system will help the grid and users to achieve large-scale multi-energy complementarity.

c. Demand-side Optimization: Demand-side optimization is a completely demand-side approach that aims to directly engage energy end-users in "energy conservation, consumption reduction, and cost savings." To achieve this goal, energy services are fully integrated on the user side, and users have a high degree of participation and autonomy. On the energy user side, "everyone participates, everyone contributes, and everyone benefits" is achieved for energy conservation and emission reduction. User-side distributed energy, user-side distributed storage, and digital energy management services focus on helping the user side achieve the coordinated efficiency of multiple secondary energies, and improve energy efficiency.

The Wuhan Artificial Intelligence Computing Center, supported by Huawei Digital Power FusionDC, has saved 40% of the power supply area and improved efficiency by more than 3.5% through modular design, the combination of energy storage and digital technology.

d. Supply-demand Coordination Optimization: Supply-demand coordination optimization refers to the process or ability of coordinating two or more different resources or individuals to work together to achieve a certain goal. In a system built on distributed energy, not only can various distributed energy be coordinated on the demand side, but the supply side and demand side can also be coordinated and echoed. Let the demand respond to the supply, rather than the supply side unilaterally responding to the fluctuations of the demand side. Combined with distributed storage, resources can be jointly optimized and configured. The energy internet is to realize effective demand response through information systems, and solve the problem of supply-demand interactive coordination configuration.

3.3.2 Urban Transportation

According to the World Resources Institute (WRI) "Decoding China's Provincial Transport Carbon Emissions from 2012 to 2019", China's transport carbon emissions account for about 9.2% of emissions from energy activities. In provinces with developed economies or a large proportion of the tertiary industry, such as Beijing, Shanghai, and Hainan Province, transport carbon emissions accounted for more than 20% of energy-related emissions in 2019.

As China's urbanization process continues to accelerate, cities are becoming larger and larger, and the efficiency of urban transportation is declining year by year, with more and more congested roads. This greatly hinders the process of net zero carbonization in the urban transportation sector. Traditional transportation management methods are no longer able to meet the growing transportation demand. Intelligent transportation systems, by using modern information technology and intelligent means, can effectively improve traffic flow rate, improve traffic resilience, and optimize road resource utilization. In the "carbon peaking" stage, it can play an important role. Combining with innovative electrified public transportation systems to achieve the net zero carbonization of urban transportation will continue to promote the realization of "carbon neutrality" in the urban transportation sector.

a. Optimizing Traffic Management: Urban Traffic signals clearly inform drivers of the allocation of traffic rights through the change of colors, automatically control and manage intersections, and automatically allocate and control conflicting traffic flows, reducing the occurrence of traffic accidents. While it brings safety, it also has a significant negative impact on the traffic efficiency of urban transportation, such as: extending the traffic delay time at low-traffic intersections and reducing traffic efficiency. Therefore, by collecting and analyzing multi-dimensional data such as road traffic flow, traffic volume, and peak and valley periods, and implementing dynamic signal timing in a coordinated manner by region, the traffic flow control characteristics of traffic signals can be fully utilized to ensure the safety of road intersection traffic while improving road traffic efficiency, alleviating urban traffic congestion, and effectively reducing the overall carbon emissions level of urban transportation.

The intelligent traffic signal control system implemented by The North China University of Technology , through the integration of access and integration of traffic signal lights and signal systems from manufacturers such as Siemens, Telvent, Hisense, Actra, and SCOOT, realizes Beijing's heterogeneous signal control system, and realizes the integration of high-definition video detection and control systems on the same platform, reaching the unified and coordinated control of traffic flows, including the green wave belt on Chang'an Avenue, which has improved the traffic efficiency of Chang'an Avenue and its extension lines, and effectively reduced the traffic carbon emissions in the area.

Figure 3-13: Beijing Second Ring Road Traffic Signal Control System Interface Source: Beijing Key Laboratory of Intelligent Control Technology for Urban Road Traffic, North Polytechnic University

b. Accelerating the Electrification of Public Transportation: COP26 is the most important climate conference since the 2015 Paris Agreement (COP21). At the COP26 conference, world leaders have focused on investment in electric vehicles, but the conference statement said that reducing the use of diesel and gasoline cars cannot be the only way to reduce carbon emissions. Governments also need to increase the use of public transportation. The conference statement said: "Improving, expanding, and decarbonizing public transportation is one of the most direct and powerful ways to reduce greenhouse gas emissions." C40 Cities Climate Leadership Group and the International Transport Workers' Federation (ITWF) said at the conference, "If public transportation investment is not doubled or travel is not transitioned to zero-emission public transportation by 2030, countries will not be able to achieve the urgent goal of halving emissions in the next decade and limiting global warming to 1.5 degrees Celsius."

BYD's SkyRail system, which is electrified and has no contact rails, uses factory-prefabricated track beams for all lines, which are installed on-site. The construction cycle is short and has little social impact, reducing carbon emissions during the construction phase. The entire line uses renewable steel, which can be recycled and reused. The SkyRail is powered by blade batteries, and the entire line uses a non-electrical contact rail design, which has a high safety system and good stability. Through a smart energy management system and advanced energy-saving technology, the SkyRail single unit consumes only 0.5-0.6kwh per kilometer, which is only 13% of the average level in the rail industry. It improves the efficiency of urban public transportation and helps to achieve net zero carbonization of public transportation systems."

3.3.3 Buildings

According to the data of the China Building Energy Conservation Association's "2022 Building Energy Consumption and Carbon Emissions Research

Figure 3-14: BYD Skyrail System Source: Photo by author

Report", the total carbon emissions from urban construction in China in 2020 was 50.8 billion tCO2e, accounting for 50.9% of national carbon emissions. Of these, carbon emissions from the construction materials production stage were 28.2 billion tCO2e, accounting for 28.2% of the national carbon emissions total; carbon emissions from the construction stage were 1 billion tCO2e, accounting for 1% of the national carbon emissions total; carbon emissions from the building operation stage were 21.6 billion tCO2e, accounting for 21.7% of the national carbon emissions total; and by building type, carbon emissions from the operation phase of public buildings were 8.3 billion tCO2e, accounting for 38%.

Therefore, under the background of the "Dual Carbon" goals, intelligent management and green development of buildings will undoubtedly become one of the important tasks in China's process of peaking carbon emissions and achieving carbon neutrality.

In the planning and design stage of buildings, digital twin and other information technology can be used to implement carbon emission evaluation and management of the entire life cycle of buildings. For newly built buildings, energy-saving and environmental protection design should be carried out early in the planning and design process, and the expected threshold for carbon emissions during the operation phase of buildings should be moved forward to achieve early regulation of building carbon emissions. Through the evaluation and regulation of energy consumption and carbon emissions of public buildings, a corresponding low-carbon and net-zero carbon building assessment system can be established, the carbon emissions of buildings can be made transparent, and a sound green and low-carbon regulatory system for public buildings can be established to cultivate social awareness of voluntary energy conservation and emission reduction.In the operation phase of buildings, the use of a variety of active and passive energy-saving and carbon reduction technologies is encouraged, and key energy-consuming equipment in the fields of building heating, cooling, lighting, and power is encouraged to be upgraded and transformed to save energy and reduce carbon emissions, thereby improving the energy efficiency of equipment and promoting the greening of buildings. The use of renewable energy should be promoted, and BIPV and BAPV photovoltaic buildings should be developed to promote the popularization of electrification and light, storage, direct current, and flexibility technologies to reduce the overall carbon emissions of buildings. Through digital technology such as the Internet of Things, 5G, and artificial intelligence, the sub-item metering of building energy should be improved, and the fine-grained management of building comprehensive energy should be strengthened to achieve efficiency optimization of building energy demand.

a. Implementing Building Life Cycle Carbon Emission Assessment and Management: Establish building carbon emission evaluation methods, tools, and standards for the entire life cycle (material production, construction, operation, and demolition). In the building design stage, consider the principles and methods for determining the boundary scope of building carbon emission evaluation, and establish an evaluation model. Realize the optimization and selection of the carbon emission reduction effects of various technical measures in the scheme stage, and quantitatively calculate the unit area carbon emission reduction cost of different technical schemes, and advance the carbon emission management and evaluation of new buildings.

The building carbon emission evaluation and management system for residential buildings developed by the Beijing Tsinghua Tongheng Planning and Design Institute for the China-Swiss Dingfeng Group helped the China-Swiss Dingfeng Group to achieve the calculation and evaluation of the carbon emissions of the building project for the entire life cycle in the project planning and design stage, including: the calculation of implicit carbon emissions of building materials, and the evaluation of energy consumption and carbon emissions during operation of construction schemes (under different operating conditions). These core functions help enterprises to accurately calculate the implicit carbon emissions of buildings in the building design stage, and at the same time, to effectively evaluate and control the energy consumption and carbon emissions of buildings after construction in the planning and design stage.

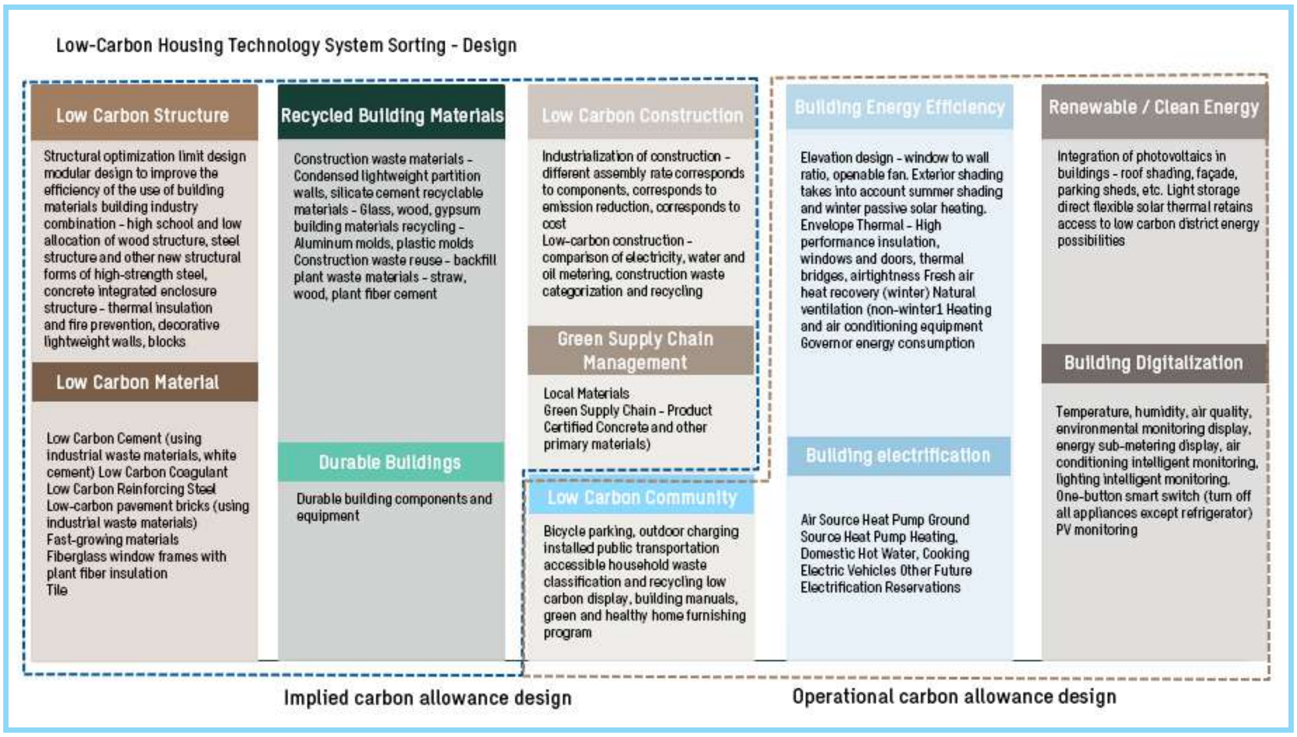


Figure 3-15: Full Life Cycle Carbon Management Source: Tsinghua Tongheng Institute of Planning and Design, Beijing

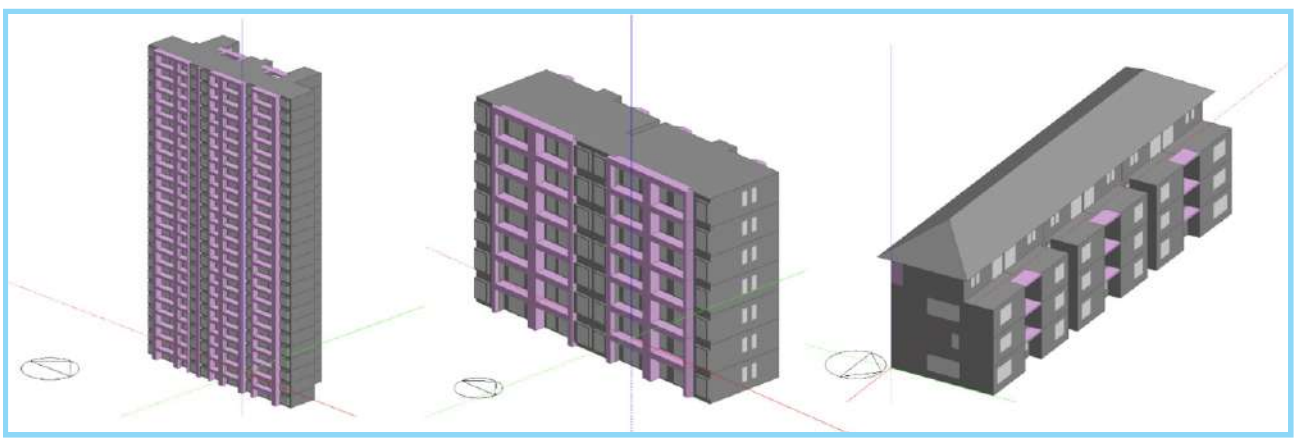


Figure 3-16: Full Life Cycle Carbon Management for Buildings Source: Tsinghua Tongheng Institute of Planning and Design, Beijing

Figure 3-17: Full Life Cycle Carbon Management Source: Tsinghua Tongheng Institute of Planning and Design, Beijing

b. Public Building Energy Consumption and Carbon Emissions Monitoring: The General Office of the CPC Central Committee and the General Office of the State Council clearly proposed in the "Opinions on Promoting Green Development of Urban and Rural Construction" (2021.10) that "implement a unified green building identification system, establish a data sharing mechanism for urban building water, electricity, gas, and heat consumption, and improve building energy consumption monitoring capabilities." The Ministry of Housing and Urban-Rural Development of China has included building energy consumption and building energy intensity indicators in the city inspection index system in the past years.

Public building operation phase carbon emissions of 830 million tCO2e, accounting for 38% of the total building operation phase carbon emissions. For the energy conservation and emission reduction of public buildings, we can rely on big data + artificial intelligence technology to establish a comprehensive building green development evaluation system covering economy, ecology, life, and safety. The evaluation method of building energy conservation and reduction is set based on problem-oriented, goal-oriented, and result-oriented. On the basis of normalized data monitoring and comprehensive evaluation, carbon emission project implementation should be achieved by "precise treatment, one building, one policy". Innovate contract energy management and other concentrated energy management modes, maximize the investment return rate of building energy conservation projects, stimulate the willingness of building managers to save energy and reduce carbon emissions themselves, and leverage social capital to participate in public building energy conservation and carbon reduction project investment.

c. Accelerating Energy-saving and Carbon Reduction Transformation of Key Energy-Consuming Equipment: In public buildings, heating, ventilation, and air conditioning (HVAC) is the main source of carbon emissions during operation, accounting for over 50% of the total energy consumption and carbon emissions of buildings in China. Therefore, it is necessary to accelerate the energy-saving and carbon reduction transformation of these energy-intensive equipment. This can be done by upgrading and renovating using technologies and products such as high-efficiency multi-split systems.For example, building water supply and air conditioning equipment are important equipment with high usage frequency. It is recommended to use variable frequency technology to improve the operating efficiency of water supply and air conditioning systems, reduce resource consumption, and at the same time, recover the waste heat from air conditioning systems.

Another major energy consumption of buildings is the mechanical system. Elevators are essential mechanical equipment in high-rise buildings. To ensure the normal travel of residents and optimize the riding experience, carbon fiber ropes can be used to improve the efficiency of elevator operation when designing the electrical system of the elevator. At the same time, the elevator system can be linked through information technology. Under the non-linked setting, when a resident presses the elevator button, two elevators on the same floor will respond and stop at the resident's floor. Through the linked setting of multiple elevators, when the button is pressed, the elevator closest to the resident will respond and stop at that floor. This will reduce the empty rate of the elevator, effectively reducing the energy consumption and carbon emissions of the elevator.

Midea Building Technology has implemented a number of energy-saving and carbon reduction measures at the Shanghai Citigroup Building, including updating and upgrading key energy-consuming equipment, comprehensive renovation of machine rooms, load simulation, construction simulation, and prefabricated construction. These measures have shortened the on-site construction period to within three months, increased the comprehensive energy savings by more than 35%, and shortened the overall investment payback period to within three years.

Figure 3-18: Energy efficient equipment Source: Midea Building Technology

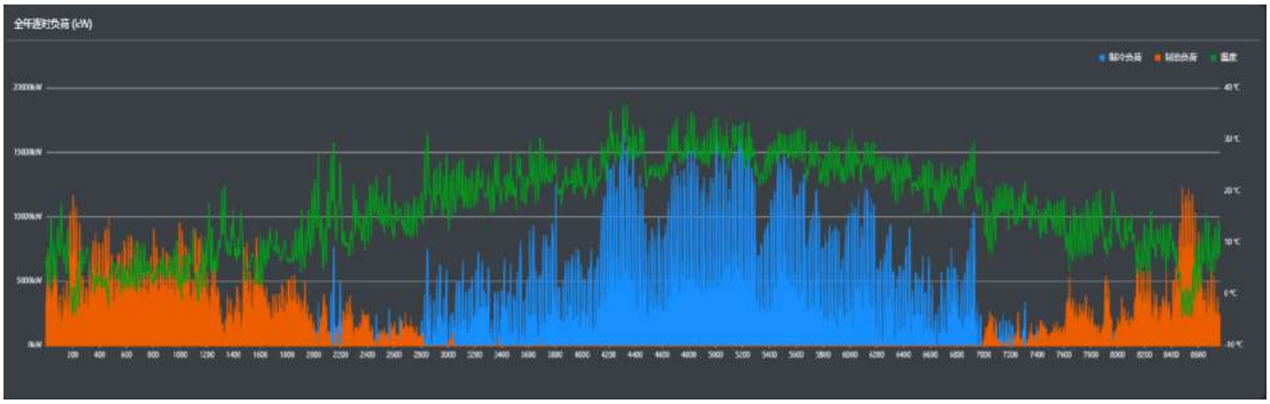


Figure 3-19: Simulation of energy-using equipment loads Source: Midea Building Technology

d. Promoting Building Renewable Energy Replacement: For building renewable energy replacement, BIPV (Building Integrated Photovoltaic) and BAPV (Building Attached Photovoltaic) models can be adopted for building renewable energy replacement, according to the type of building and the construction stage. Both are branches of distributed photovoltaics. BAPV is mainly applied to roofs, and ordinary photovoltaic modules are fixed on steel sheet or concrete roofs by brackets. BIPV is photovoltaic building integration, which integrates photovoltaic power generation devices into the building, making it an organic whole with both architectural and power generation functions. In addition to roofs, it can also be used as photovoltaic curtain walls, photovoltaic shading, and photovoltaic greenhouses, with more application scenarios.

Since China has abundant building roof resources and are widely distributed, the development and construction of rooftop distributed photovoltaics has great potential. In the field of renovation of existing buildings, BAPV is more suitable and cost-effective. For industrial and commercial factories, public buildings, parking sheds, and charging station roofs, BIPV is more likely to be applicable, bringing higher cost-effectiveness and better appearance. In the field of new buildings, BIPV is much more suitable than BAPV. Therefore, BIPV has more obvious advantages in the long run.

At the same time, in the planning of building distributed photovoltaics, from the perspective of urban systematicity, it can be considered by using information technology, comprehensively considering geographical, climatic and other lighting conditions, combining the shape of the building and the roof layout, and it is best to coordinate the installation and planning, so as to obtain an effective forecast of power generation and benefits in the planning stage.

The Beijing Daxing International Airport Smart Photovoltaic System, built by Huawei Digital Power, is a distributed photovoltaic power generation project on the roofs of the airport cargo area, east runway, and business aviation area. The construction scale is 5.61MWp. After grid-connected operation, it can provide 6.1 million kWh of green electricity to the grid annually, which is equivalent to saving 1,900 tons of standard coal annually, reducing 966 tons of carbon dioxide, and reducing 14.5 tons of sulfur dioxide.

e. Strengthening the Construction of Digital Energy Management Systems (Ems): From the perspective of building system energy saving and carbon reduction, commercial light, storage, direct, and flexible solutions can be developed for public buildings. By building a building energy digital management system (EMS), real-time data from building equipment such as photovoltaics, energy storage, cold storage, direct current charging piles, and electrical equipment loads can be collected and uploaded to the cloud. This will realize the coordinated control of the energy system, carbon management system, and intelligent building operation and management center. Through flexible control algorithms, source and load interaction can be realized, and fine-

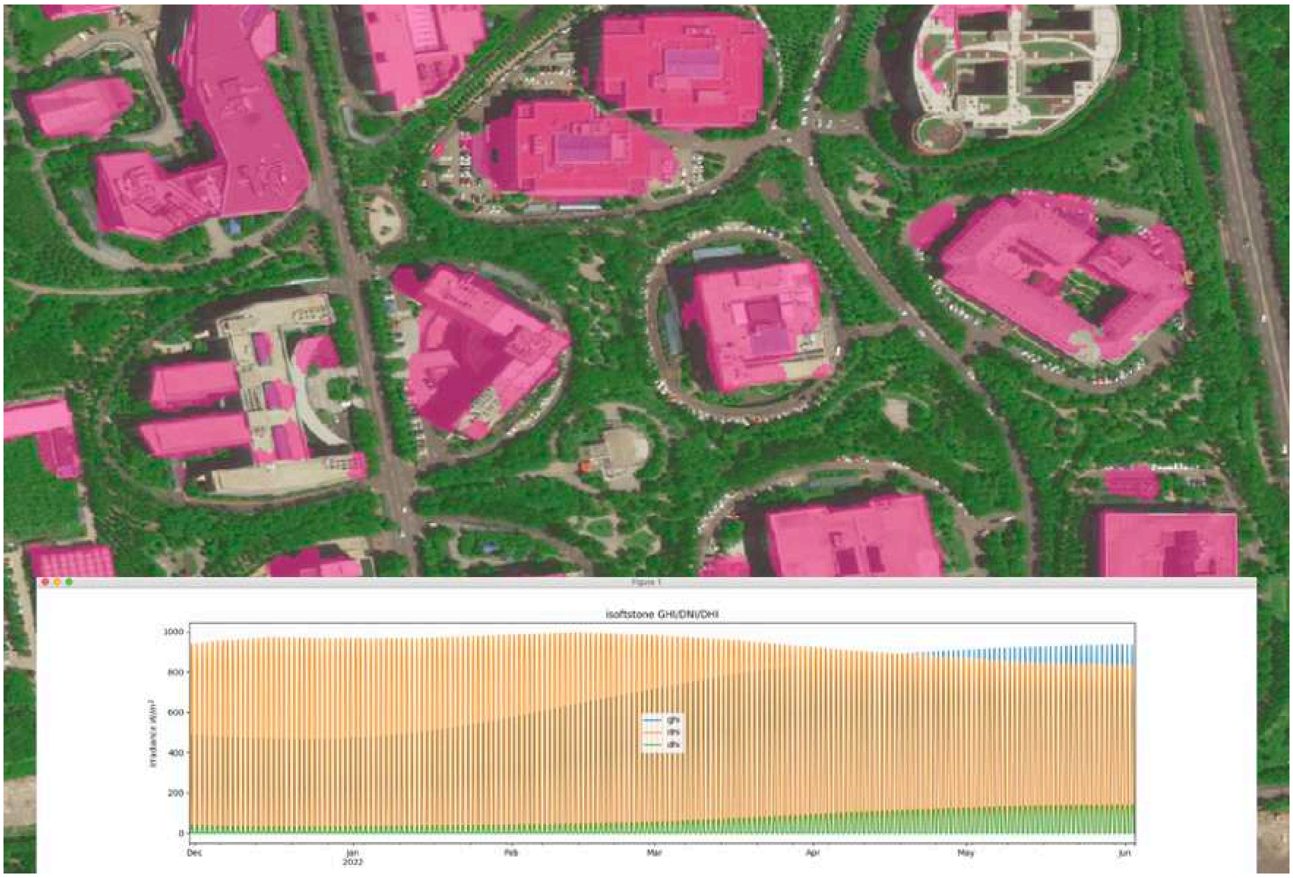


Figure 3-20: AI Roof Area and PV Revenue Measurement System Source: ISSTECH

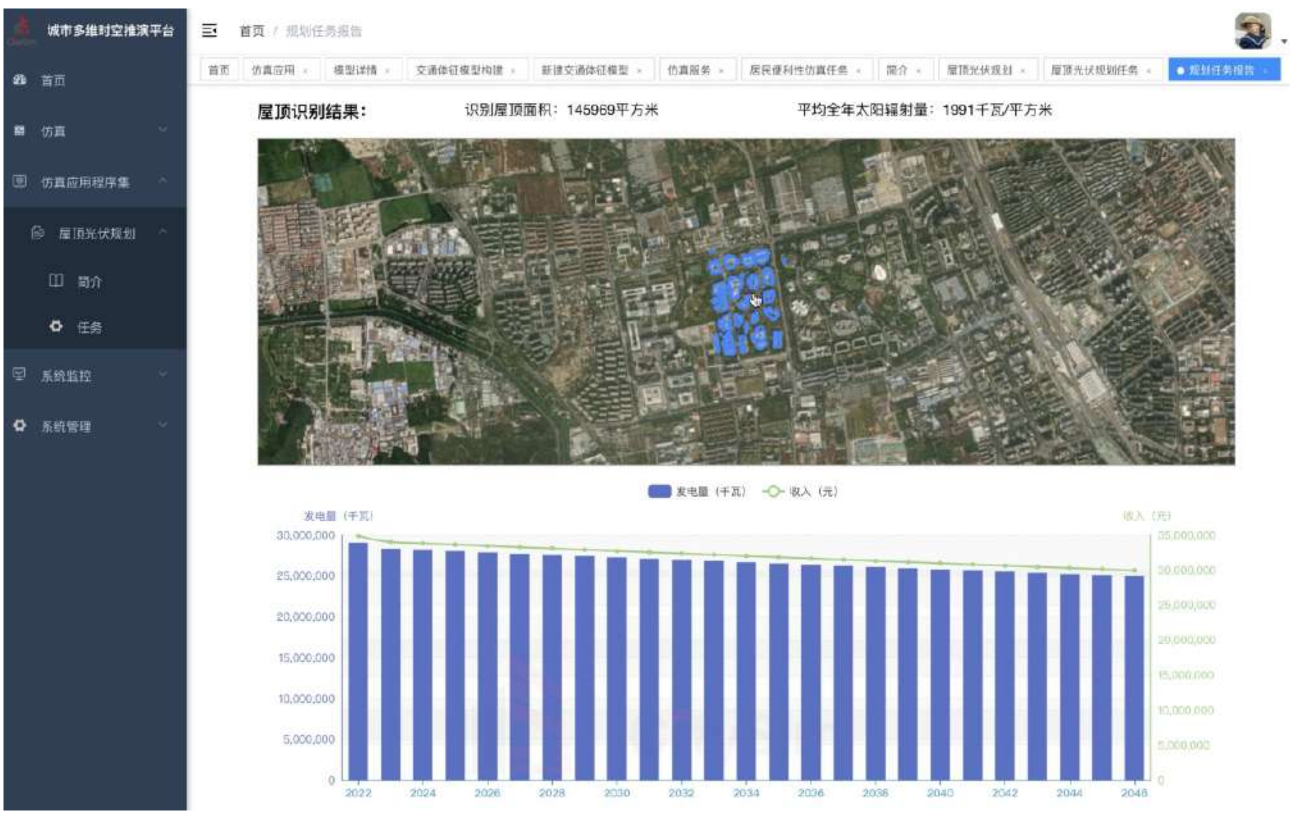


Figure 3-21: AI Roof Area and PV Revenue Measurement System Source: ISSTECH

grained management can be implemented:Dynamically adjust the charging and discharging strategies of the energy storage system to improve the overall efficiency of the system.Through energy storage strategies, peak shaving and valley filling can be achieved to save energy costs.

Midea Building Technology has implemented a self-developed diagnostic algorithm in the Midea Group headquarters building to monitor and evaluate the dynamic performance data of energy-consuming equipment, diagnose and analyze the energy consumption and carbon emissions of equipment in real time, and optimize and coordinate control to achieve the goal of system efficiency improvement and energy saving and carbon reduction through fine-grained management.

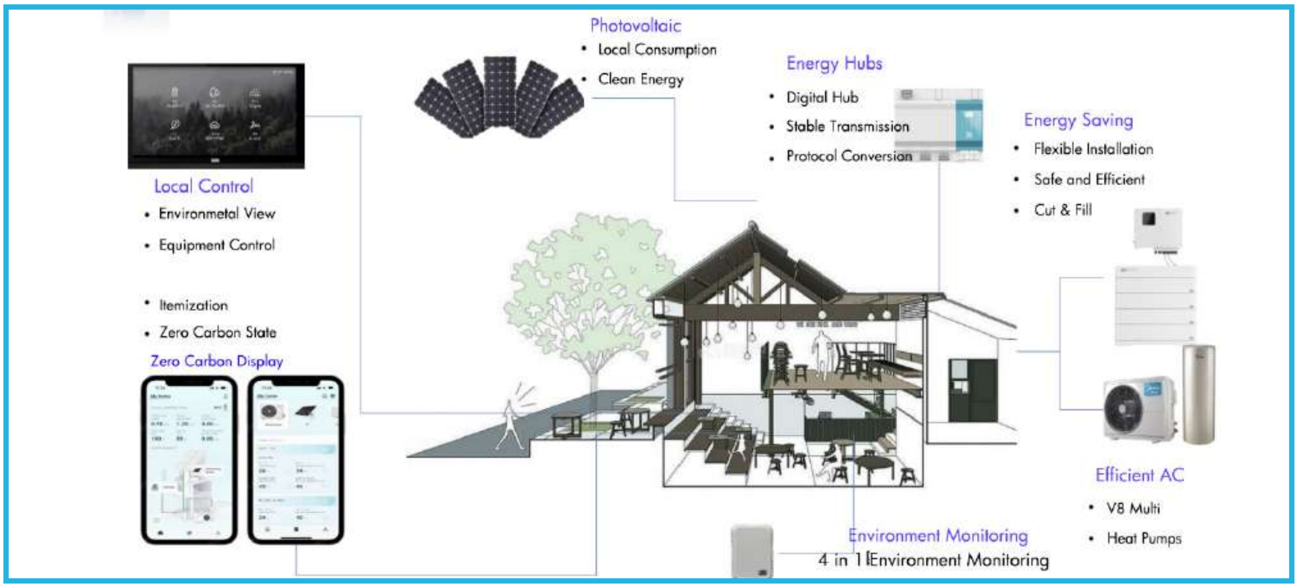


Figure 3-22: Digital Energy and Carbon Management System for Buildings Source: Midea Building Technology

Figure 3-23: Digital Energy and Carbon Management System for Buildings Source: Midea Building Technology

3.4 Summary

Digital technology plays an important role in the process of achieving net zero carbon in cities. On the one hand, it can be used as a tool for planning urban carbon reduction strategies, mastering the city's carbon balance point and the progress of "carbon peak and carbon neutrality". On the other hand, it also plays an important role in improving the overall operating efficiency and energy conservation and carbon reduction in key carbon emission areas such as energy, transportation, and buildings.

This chapter elaborates on the roadmap for achieving net zero carbon in cities by proposing three steps: mastering carbon data, developing carbon strategies, and taking smart carbon actions.

1 Mastering Carbon Data

This section describes the construction of the urban carbon data base. By leveraging big data and IoT technologies to promote real-time collection, accurate calculation, and traceability of carbon emissions data, and by selecting scientific and reasonable carbon accounting perspectives and carbon emission collection methods, accurate accounting of carbon footprints for all basic carbon emission units in cities and their cross-border carbon footprints can be achieved, which helps to clarify the city's carbon emissions responsibilities in the national and even global supply chains. At the same time, under the support of data, building a "dual carbon" brain and using AI technology to model emission data can help relevant decision-makers in cities to formulate timely and efficient urban carbon emission management strategies, and improve the systemic efficiency of operation in all areas of the city.

2 Formulating Carbon Strategies

This section describes In seeking the best possible urban carbon strategy, it is necessary to seek a dynamic balance between energy, environment, economy, and society, and promote the long-term sustainable development of society. Building a city carbon management positive feedback closed-loop management mechanism and model with the goal of coordinated development of multiple aspects such as energy, industry, development model, pollution control, resident health protection, and social livelihood, is of great significance to the decision-making support for achieving net zero carbon in cities.

At the same time, due to the vast territory, complete industrial chain, and widespread distribution of China, the industrial structure and natural resource endowment vary greatly in different regions. This determines that the action plans for the "dual carbon" goal should be differentiated and personalized. Therefore, in the development policies for "dual carbon", we should not pursue "one-size-fits-all" or "herd mentality". The realization of the "dual carbon" goal should be coordinated throughout the country to form a synergistic effect of systematic reduction of carbon emissions.

Finally, to address the complexity and systematicity of the "carbon peak and carbon neutrality" goal, we need to incorporate the concept of system into the whole process of "dual carbon", and focus on handling the four relationships between development and reduction, overall and local, long-term and short-term, and government and market.

3 Smart Carbon Actions

Finally, taking smart carbon actions in the energy, building, and transportation sectors, empowered by digital technologies, is an important part of the roadmap for achieving net zero carbon in cities, and ultimately achieving net zero carbon in cities.

Case Studies

04

This chapter will demonstrate 5 urban cases and 5 enterprise cases, which apply digital technologies and smart city solutions in empowering the transition to low carbon and net-zero carbon cities and communities.

Chapter 4

4.1 City Cases

4.1.1 Shanghai Zhenru Sub-Center: Max City and Haina Engineering Institute Project - Digital Innovation Empowering Net Zero Carbon in Buildings

1. Background

Zhenru Sub-Center is located in Putuo District, Shanghai, covering a planned area of 6.16 square kilometers. It aims to construct a multifunctional, culturally diverse, and ecologically innovative urban reception hall, aligning with the direction of the United Nations Sustainable Development Goals. In terms of low-carbon construction, Zhenru Sub-Center, through improving organizational structures and advancing mechanisms, gradually strengthens its foundational low-carbon capabilities and management efforts. In July 2023, it was honored with the title of Shanghai Low-Carbon Development Demonstration Zone. The Max City Project and Haina Engineering Institute Project have rich experience in digitally empowering low-carbon and net-zero development, making them excellent project driven by digitization.

2. Max City Project

Adhering to the architectural design goal of “near-zero carbon,” the Max City project employs industrialized construction and integrated intelligent interiors. This approach incorporates green and sustainable ecological design, low-carbon sustainable electromechanical equipment, and intelligent sustainable management systems to achieve the ecological construction of the project.

Project Objectives

Figure 4-1: Zhenru Building Intelligent Integrated Management Platform
Source: Shanghai Zhenru

Achieve “near-zero carbon” buildings through industrialized construction and intelligent interiors. Implement green and sustainable ecological design, low-carbon sustainable electromechanical equipment, and intelligent sustainable management systems.

a. Green Ecological Design: Integrating Zhenru Port and green corridors, the project adopts measures such as sunken green spaces, green roof installations, and rainwater storage to increase site runoff coefficients and the annual runoff pollution control rate. This creates a safe and resilient sponge base, improving microclimates.

b. Low-Carbon Electromechanical Equipment: Utilizing advanced VAV variable air volume central air conditioning systems, small-capacity chillers, and other equipment to achieve a reduction of over 20% in air conditioning energy consumption. The project uses high-efficiency energy-saving equipment to improve the efficiency of chillers and boilers.

c. Intelligent Management System: Applying smart maps, indoor positioning navigation, and passenger flow management systems to achieve user navigation, statistical analysis, and energy management platforms. This reduces building air conditioning

Figure 4-2: installment of photovoltaic system
Source: Shanghai Zhenru

energy consumption and envelope structural loads, resulting in an annual electricity savings of over 8% and a year-on-year reduction of 16% in carbon emissions.

3. Haina Engineering Institute Project

Project Features

As a landmark project in the digital transformation of Shanghai, Haina Engineering Institute Project is famous for its innovative solutions with "low-carbon + digitalization," achieving optimal utilization of internal building resources and energy.

a. Photovoltaic System: The project incorporates a Building-Integrated Photovoltaic (BIPV) system along with Building-Attached Photovoltaic (BAPV), covering over 30% of the total roof area. The annual electricity generation exceeds 130,000 kWh, effectively meeting the year-round lighting and power requirements.

b. Low Carbon Goals: Leveraging the core technology of "light storage and direct flexibility," the project achieves the goal of "carbon-neutral buildings," reducing building energy intensity by more than 20% and achieving an annual carbon reduction of over 50 tons through renewable energy.

c. Digital Applications: Real-time monitoring of energy consumption is carried out using sensors and IoT technology, establishing a digital carbon emissions data platform. Smart grid technology is employed to regulate energy utilization projects. The Green Smart Building Automation System achieves automatic control of internal space usage, providing the optimal power supply solution, extending equipment lifespan, and significantly saving energy and human resource costs.

These two projects collectively demonstrate the positive effects of digital innovation on achieving net-zero carbon in buildings, providing valuable experiences for low-carbon development.

4.1.2 Wuhan: Urban Ventilation Cooling and Low-Carbon Practices

1. Background

Wuhan has undertaken the interdisciplinary and challenging task of studying the urban wind environment, primarily based on two factors: policy guidance and practical demands. China has devoted itself to build ecological urban future. The China Meteorological Administration clearly states in its "Order No. 18: Climate Feasibility Management Method" that climate feasibility assessments should be conducted in urban and rural planning, key areas, or regional development and construction planning. Urban wind environment research will be a key area in future planning and design research.

At the same time, the urban heat island problem is becoming more severe in Wuhan, with the city's average summer temperature rising by 2 degrees Celsius. The number of days with temperatures exceeding 35 degrees Celsius has reached 22, and the number of hazy days has reached 99. Strengthening the digital research on urban wind environment plays a significant role in reducing the heat island effect, promoting the spread of air pollutants, and improving the microclimate in public spaces.

This research aims to understand the current wind environment characteristics of Wuhan based on the wind environment within the third ring road of the main urban area of Wuhan. Utilizing historical observational data from 117 meteorological stations provided by the city's meteorological bureau and the three-dimensional models of terrain and buildings from the city's planning bureau, a quantitative analysis method using Computational Fluid Dynamics (CFD) is employed. With the support of the SWIFT model, the analysis and simulation of the urban wind environment are conducted at a resolution accurate to the meter level. The study validates the designated secondary wind corridor system of Wuhan from a multidisciplinary perspective and quantitative research techniques. Simultaneously, it proposes planning guidance and optimization measures to improve the microscale wind environment of specific urban blocks.

2. Main Contents

Five Main Aspects

a. Aquirement of Data: Collaboration with the meteorological bureau to acquire meteorological data from 116 stations citywide, pioneering the establishment of a spatialized comprehensive meteorological database for the entire city. Drawing inspiration from the Parisian experience, a Computational Fluid Dynamics (CFD) simulation model for Wuhan's wind environment is developed.

b. Specific Planning: Exploration of spatial planning strategies and designs guided by optimal wind environments.

c. Software Invention: Development of systems (software) for wind environment impact assessments and the establishment of related standards.

d. Simulation of Key Areas: Alignment with the needs of planning and management work, simulation of wind environment indices for key areas and yet-to-be-developed land parcels, and formulation of planning and design requirements.

f. Assessment and Suggestions: Simulation assessment of existing planning and design projects in specific regions, proposing improvement requirements and suggestions based on optimal wind environments, and assisting the planning bureau in decision-making for plan approval.

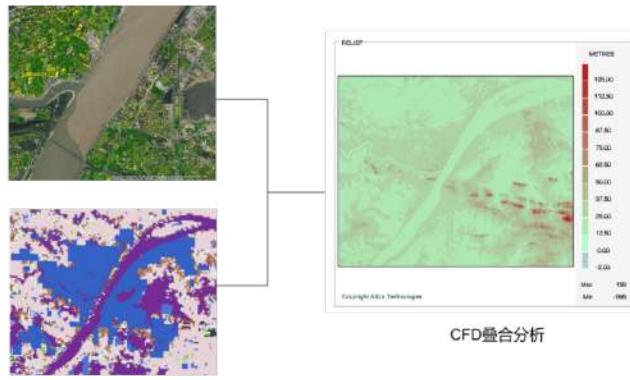


Figure 4-3: Wuhan City Wind Environment Simulation Model Schematic Diagram Source: WPDI

Six Major Innovations

Establishment of the Wuhan City Wind Environment Basic Database: Through collaboration with the meteorological bureau, meteorological data from 116 stations citywide were obtained, marking the groundbreaking creation of a spatialized comprehensive meteorological database for the entire city.

a. Clarification of Current Wind Mechanisms: The assessment of the wind environment requires typical time points and reference standards. This study, using the analysis of the wind environment basic database, identified 12 wind mechanisms and summarized three typical wind mechanisms that collectively account for over one-third of the year, using the standard of the coldest day of the year for solar radiation evaluation.

b. Utilization of the SWIFT Mathematical Model for CFD Quantitative Simulation: Quantitative simulation of the wind environment in the main urban area was conducted using the SWIFT mathematical model. Meteorological data, terrain data, and current urban construction data were overlaid and analyzed through CFD, producing high-precision simulation results for the entire city. With the aid of supercomputers, the simulation results achieved an accuracy of 4m by 4m, laying the groundwork for future analyses at the microscale, including at the level of city blocks and even buildings.

c. Quantitative Analysis and Verification of Existing Wind Corridor Systems: Quantitative analysis and verification were performed for the existing first and second-level wind corridors in the main urban area. The study focused on planning optimization and enhancement of the second-level wind corridors, proposing corresponding planning and control measures.

d. Identification of Impact Indicators for Urban Wind Environment Optimization: Through linear regression analysis, the study identified clear positive correlations between meteorological indices such as comfort, local climate, air diffusion, and planning indicators like volume ratio, building density. These correlations were established as the basis and reference for adjusting planning and design projects.

e. Optimization and Adjustment of Microscale Block Planning: Using specific planning projects as examples, before adjustments, there were uncomfortable high-speed winds and stagnant winds at both near-ground and 22-meter high altitudes. However, through planning optimization strategies such as increasing open spaces, green areas, adjusting building spacing, volume, height, and layout combinations, the continuous simulation results over 24 hours show an improvement in the wind environment experience, both near-ground and at higher altitudes.

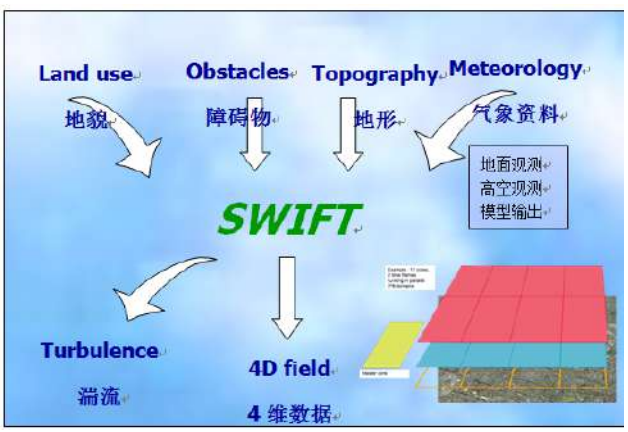


Figure 4-4: Wuhan City Wind EModel Analysis Diagram
Source: WPDI

3. Relevance to SDGs

This entire project primarily corresponds to SDG11: make cities and human settlements inclusive, safe, resilient and sustainable; and SDG13: climate action. Addressing climate change has become a formidable challenge in achieving sustainable development. Presenting affordable and scalable climate change solutions will ensure that the progress made in recent decades will not stagnate due to climate change, and it will safeguard economic health and resilience.

4. Summary and Reflection

The outcomes of this project not only apply to the specific practices of planning optimization and microclimate improvement in sensitive areas of Wuhan but also contribute to the formulation of the city-wide Ventilation and Cooling Action Plan. Furthermore, the data-supported planning and design have paved the way for scientifically and reasonably conducting planning management, opening up new directions. The content of the achievements has also been awarded the inaugural "China-Europe Green and Smart City Technology Innovation Award," aimed at recognizing projects with innovative significance in the fields of green and smart cities.

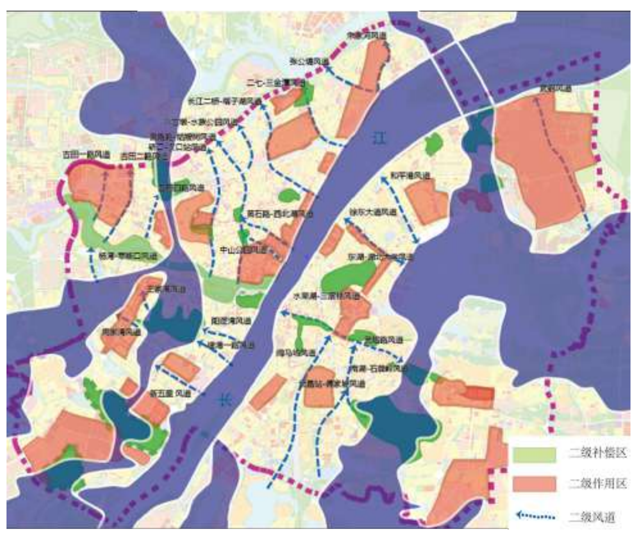


Figure 4-5: Wuhan City Wind EModel Analysis Diagram
Source: WPDI

4.1.3 Shenzhen: Yantian District's Digital Energy Community Carbon Reduction Practice

1. Background

With the acceleration of urbanization and industrialization, the depletion of non-renewable energy has led to an increase in carbon emissions. During the process of urbanization, a large number of ecosystems are transformed into urban land, which result in the loss of habitats and extreme weather. As the urban population grows, the amount of waste generated is also increasing, and waste that is not properly processed and utilized produces large amounts of greenhouse gases. To reduce carbon emissions, Yantian District has implemented the Dual Carbon Brain platform, microgrid systems, energy management systems, and black soldier fly kitchen waste treatment and promote urban biodiversity conservation and energy conservation to achieve carbon reduction

2. Main contents

a. Dual Carbon Brain Platform: The Meisha community in Shenzhen pilots the "Dual Carbon Brain" platform, achieving dynamic control of carbon emissions across various districts in Shenzhen through electric carbon monitoring. After two years of operation, the platform covers Yantian District's enterprises and buildings, including emission-controlled enterprises, regulated enterprises, and terminal enterprises in industrial parks, accomplishing carbon accounting and data monitoring. Yantian District's buildings were the first to automatically collect and calculate carbon emissions and energy consumption indicators, launching the nation's first residential low-carbon electricity application. It guided 15,000 households to open carbon accounts, reducing carbon emissions by nearly 300 tons. The platform continuously monitors the nearly-zero carbon construction in the Dapeng Meisha community, including carbon emissions, new energy capacity, and electricity consumption, providing robust support for community carbon management and emission reduction.

b. Energy Management System: The Energy Management System is a comprehensive energy management platform that enables the statistical, predictive, and comparative analysis of energy consumption for specific regions and devices. It calculates corresponding carbon emissions and

Figure 4-6: Homepage of Dual Carbon Brain
Source: Vanke Foundation

serves as the foundation for monitoring, managing, and setting emission reduction paths for regional and device carbon emissions. Both of these technologies have been applied in the Vanke Center Park in Yantian District, achieving intelligent management of energy use and carbon emissions in the park.

c. Microgrid System: The microgrid system is an intelligent system for local electricity generation, transmission, distribution, and storage. In the Vanke Center Park, by updating building equipment and introducing new energy technologies, the clean energy generation capacity has been successfully increased by 55%, achieving a comprehensive energy-saving rate of 85%. The system uses smart meters to monitor various areas of the park in real-time and, combined with user habits, implements intelligent management to reduce overall energy consumption. Its model algorithm utilizes machine learning to predict the 24-hour electricity consumption and generation curve, devising a power supply strategy for maximizing economic benefits. The system has been in operation for nearly 2 years, providing the park with reliable and efficient energy management.

Figure 4-7: Carbon Emission Monitoring and Management System in the Construction Sector Source: Vanke Foundation

d. Black Soldier Fly Kitchen Waste Treatment Technology: The black soldier fly kitchen waste treatment technology has successfully processed 30.8 tons of organic waste in the Vanke Center Park. This includes 24.5 tons of kitchen waste and 6.3 tons of green waste, generating 14.7 tons of organic humus. The produced humus is used for fertilizing the park and constructing rooftop gardens. The community composting technology, combined with the excrement of black soldier flies, is successfully transformed into organic humus, improving soil quality. Yantian District has established a black soldier fly treatment facility capable of handling 3 tons of kitchen waste. It is estimated to reduce emissions by 970.5 tons of CO2eq annually, with plans to gradually expand the scale of treatment facilities.

Figure 4-8: Exhibition Hall of Black Soldier station

Source: Vanke Foundation

e. Biodiversity Conservation Action: Vanke Foundation collaborated with Sun Yat-sen University to conduct a comprehensive survey of biodiversity in the Meisha area. Through observation and technological monitoring, technical support is provided for the restoration of critical habitats and the enhancement of biodiversity. Over the past year, more than 4,000 pieces of data have been collected, documenting 108 species of birds, 9 species of mammals, 29 species of amphibians and reptiles, 35 species of aquatic organisms, and 67 species of pollinating insects. Simultaneously, efforts are made to enhance community residents' understanding of animal species and their current status, promoting public environmental behavior and awareness of biodiversity conservation.

Figure 4-9:Biodiversity Rooftop Garden Source: Vanke Foundation

Innovations

This project considers the emitters, sources, and response measures, constructing an innovative solution that spans the entire lifecycle. The Dual Carbon Brain, Energy Management System, and Microgrid System monitor energy usage in real-time, providing data for energy conservation and emission reduction. Implementation involves collaborative efforts from the government, businesses, social organizations, and residents, effectively promoting carbon reduction measures such as digital monitoring platforms, AI-based electricity matching, localized kitchen waste treatment, and biodiversity conservation. Combining digital intelligence with community carbon emission sources, the project accurately displays energy consumption and demands, formulating digital control pathways and resident-engaged paths for carbon reduction and sequestration.

3. Relevance to SDGs

This digital innovation solution can effectively provide dynamic monitoring data for carbon reduction in the Yantian District community, clearly identifying the main sources of carbon emissions, and offering corresponding implementation pathways based on these sources. The implementation of innovative digital technologies such as the Dual Carbon Brain contributes significantly to strengthening ecological environmental protection and management, promoting low-carbon technologies, fostering environmental awareness among consumers and businesses, advocating for ecological agriculture, and promoting green and low-carbon urban development. It aligns with SDGs such as SDG12: Responsible Consumption and Production; SDG11: Sustainable Cities and Communities; SDG13: Climate Action; and SDG15: Life on Land.

Beneficiary Groups

The implementation of this digital innovation solution has enhanced the ecological benefits and carbon sequestration of energy usage in Yantian District, improving the living and working environment for residents. The benefits generated extend to all residents in Yantian District and the staff at Dapeng Meisha Vanke Center's Carbon Neutrality Experimental Zone. As the digital innovation solution continues to be applied, upgraded, and expanded, the quality of the community's ecological environment will further improve. The resulting benefits will also extend to the visitors coming to the Dapeng Meisha community, estimated at over six million people annually.

4. Summary and Reflection

This digital innovation solution has shown significant effects in promoting the transformation of community economic development, driving technological innovation, reducing environmental pollution, enhancing sustainable development capabilities, and contributing to global climate governance. In the future, it holds crucial significance in promoting the application of green energy in the community, fostering sustainable development, reducing environmental impacts, protecting species, promoting the health of ecosystems, providing biological resources, and boosting tourism and economic development. Additionally, it can promote the ecological service functions of communities and cities, reducing the urban heat island effect. Providing sustainable environmental and ecological services for communities and cities contributes to accumulating effective action experience for coastal communities in responding to climate challenges.

4.1.4 Chengdu High-tech Zone: Mega-City Carbon Reduction and Pollution Reduction Collaborative Efficiency Management

1. Background

In the process of pursuing the "Dual Carbon" goals, Chengdu High-tech Zone has identified challenges in its regional carbon monitoring system, lack of ecological data, and the absence of carbon emission strategy guidance for businesses. These issues have significantly impacted the construction of a green and low-carbon urban area in the region.

To address these issues, Chengdu High-tech Zone has implemented the "Carbon Reduction, Pollution Reduction, Collaborative Efficiency Enhancement" project. In collaboration with academic institutions, Chengdu High-tech Zone establish the first national demonstration zone to support local green transformation, promote high-quality development, and achieve intelligent management of "Dual Carbon," digital governance of "Triple Pollution," and foster collaborative innovation.

2. Main contents

The Chengdu High-tech Zone's Mega-City Carbon Reduction and Pollution Reduction Collaborative Efficiency Management project is built on the foundation of the perception layer. It collaborates with relevant academic authorities and higher-level authoritative units to establish a collaborative monitoring system, collaborative governance system, and collaborative regulatory system for carbon reduction and pollution reduction. This initiative aims to support the construction of a low-carbon city.

a. Collaborative Monitoring System for Carbon Reduction and Pollution Reduction: The data collection design of the collaborative monitoring system for carbon reduction and pollution reduction will unfold from point to line and further to network. It will comprise a three-dimensional network for perceiving and collecting carbon emission and pollution data in the high-tech zone through qualitative and quantitative analyses in different dimensions. By deploying small-scale and standard monitoring stations, combined with mobile aerial monitoring, handheld device monitoring, satellite remote sensing, and integration with the Internet of Things platform, a comprehensive "air-land-space" integrated three-dimensional monitoring network will be established. This aims to comprehensively construct the collaborative monitoring system for carbon reduction and pollution reduction in the high-tech zone.

b. Collaborative Governance System for Carbon Reduction and Pollution Reduction: Centered around the goals of peak carbon emissions and carbon neutrality, the collaborative governance system for carbon reduction and pollution reduction aims to comprehensively acquire data on carbon reduction and pollution reduction through digital means, scientifically grasp key areas, and economic operation data. It establishes a region-wide basic database for carbon reduction and pollution reduction emissions, refining high-value data assets through modeling, abstraction, and algorithmization. With the integration of a new institutional framework, the system constructs a statistical monitoring system for carbon reduction and pollution reduction, exploring the functionalities and value chain of data applications. It provides data support for scientifically assessing the effectiveness and systematically advancing, driving the reconstruction of governance methods, collaborating to improve environmental quality, and achieving precise management of peak carbon emissions, carbon neutrality, and economic development.

c. Collaborative Regulatory System for Carbon Reduction and Pollution Reduction: The collaborative regulatory system for carbon reduction and pollution reduction is built on the basis of data collection related to energy, carbon emissions, and other activities across various departments, industries, and key enterprises in Chengdu High-tech Zone. It involves constructing multi-dimensional analysis and prediction models, encompassing models for energy consumption and carbon emissions accounting, carbon sink accounting, analysis of emission reduction amounts and potential, estimation models for peak carbon emissions, and tracking models for carbon neutrality.

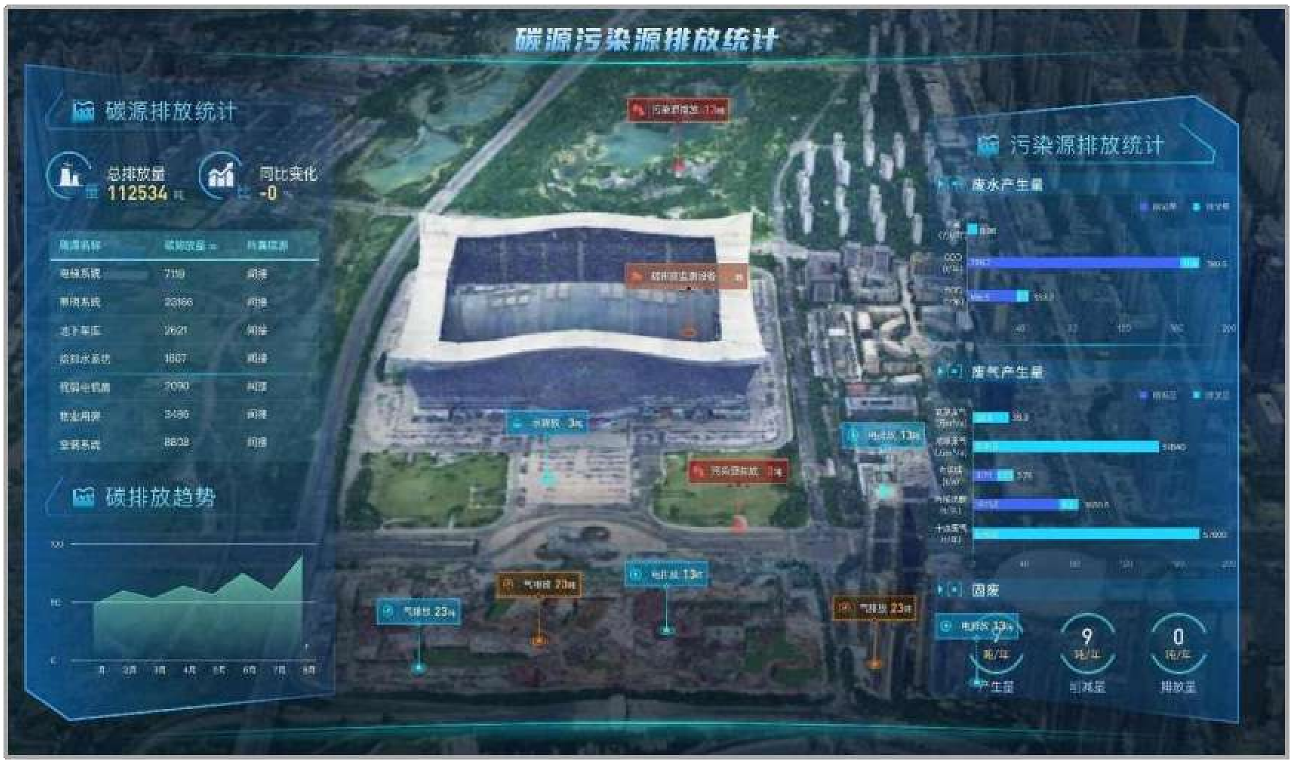


Figure 4-10 & 4-11:Chengdu Multi-level Urban Carbon Source and Pollutant Emission Statistics Source: Chengdu Vision Digital Technology Co.

3. Relevance to SDGs

The Chengdu High-tech Zone's Mega-City Carbon Reduction and Pollution Reduction Collaborative Efficiency Management project benefits both urban businesses and individuals, promoting the improvement of the regional environment and further achieving peak carbon emissions and carbon neutrality. It aids the ecological and environmental departments and personnel in working and managing more efficiently. Furthermore, the project is characterized by its integrated comprehensive carbon monitoring network, digitalized and normalized collaborative management system, cross-departmental and cross-disciplinary data integration, in-depth research on energy-saving and emission reduction technologies, a categorized guidance system for carbon reduction and pollution control policies. It is committed to achieving the United Nations Sustainable Development Goals (SDGs): SDG7 - Ensure access to affordable, reliable, sustainable, and modern energy for all; SDG8 - Promote sustained, inclusive, and sustainable economic growth, full and productive employment, and decent work for all; SDG11 - make cities and human settlements inclusive, safe, resilient, and sustainable; and SDG13 - climate action.

4. Summary and Reflection

The Chengdu High-tech Zone's Carbon Reduction and Pollution Control Management project establishes an integrated carbon monitoring network, utilizes inversion methods, and creates a standardized process to achieve real-time greenhouse gas monitoring and digital management. In collaboration with the National Ministry of Ecology and Environment and the Chengdu Environmental Science Research Institute, it optimizes technical pathways, collaborates on emission reduction control, and develops a categorized guidance system for emission reduction policies and green industrial development. Through data integration, standard objectives, and industrial strategies, the enterprise service platform promotes the green transformation of businesses.

4.1.5 Weihai: Digitally Empowering the Development of Red Property

1. Background

a. National Strategy Requirements: In response to national strategy for resolutely controlling energy consumption and implementing a priority for energy conservation, the State Council has issued the Carbon Peak Action Plan, aiming to promote the application and promotion of energy conservation and carbon reduction in our city's property management industry.

b. Innovation and Technology Leadership: With the flourishing development of digital intelligent technology and the growing demand of urban residents for digital experiences, promoting green governance in neighborhoods through smart and digital means has become an inevitable choice to achieve the dual-carbon development of the city.

c. Addressing Real Issues: In line with the overarching requirement of "exquisite cities", the Weihai Municipal Housing and Urban-Rural Development Bureau incorporates intelligent carbon reduction and emission reduction into property management services. The goal is to enhance the happiness and satisfaction of property owners and present a "new business card" for Weihai's exquisite city.

2. Main Contents

a. Building Red Property: With red property as the core, the Weihai Municipal Housing and Urban-Rural Development Bureau strives to achieve the goal of "home safety, convenient living, and comfortable environment" through the intelligent construction of residential areas. This effort promotes the transformation of community operation services towards green and low-carbon, aligning with the United Nations' goals for "sustainable cities and communities" and "climate action."

b. Digitally Empowering Weihai Red Property App: Utilizing the Weihai Red Property App to achieve standardized online services, data specifications, and controlled safety of facilities and equipment.

c. Weihai Weigao Garden Community Demonstration:

- Co-management and Co-governance: Extensive participation from the community party committee, property companies, homeowner committees, and residents for joint governance on low-carbon issues in the community.

- Digital Empowerment: Through the smart transformation in 2021, Weigao Garden Community aims for intelligence, integrating technologies such as big data, the Internet of Things (IoT), and artificial intelligence to ensure the implementability of low-carbon operations in the community.

- Smart Property: Leveraging the Red Property App to shift service standards and quality checks from offline to online, addressing management pain points and challenges, enabling data queries and

Figure 4-12 & 4-13:Smart Access systems　Source: Weihai Housing and Urban-Rural Development Bureau

Figure 4-14& 4-15:Smart Security　Source: Weihai Housing and Urban-Rural Development Bureau

Figure 4-16: Smart Energy Management Platform　Source: Weihai Housing and Urban-Rural Development Bureau

traceability, and improving homeowner satisfaction.

• Smart Access: Introducing a facial recognition access control system to enhance the convenience of homeowner access while simultaneously improving the security of community management.

• Smart Security: Through the smart property platform, integrating devices such as license plate recognition, high-altitude monitoring, and lane occupation alarms to enhance comprehensive security risk prevention.

• Smart Energy Efficiency:

- Electricity Conservation: Utilizing a smart lighting system to adjust brightness based on time and space, achieving energy savings in different time periods and areas.
- Water Conservation: Monitoring water usage through smart metering, employing drip and spray irrigation techniques for greenery to reduce water wastage.
- Waste Utilization: Introducing "Internet+" smart garbage recycling stations to motivate residents to actively participate in waste sorting.
- Consumable Conservation: Implementing IoT sensing technology to monitor equipment, replacing consumables as needed to extend their lifespan.

3. Key Achievements of Digital Innovation Development

a. Achievements in Low Carbonization Shared by All, Sustainable Concepts Deeply Rooted: Weihai issued the "Guiding Opinions on Promoting the Construction of Smart Residential Communities," requiring newly built communities to implement smart construction, and old communities are included in the smart renovation plan. A total of 607 communities have connected to the smart property platform, and they have been selected as outstanding cases in the "People-Benefiting" field of the new smart city in Shandong Province.

b. Introduction of New Technologies, Continuous Empowerment, and Ongoing Humanistic Care: Weihai is about to upgrade the smart property management 3.0, represented by AI artificial intelligence. In the face of new technological challenges, emphasis on humanism and care is continuous, positioning smart property as a beneficial empowerment and supplement to property management.

4.2 Enterprise Case Study

4.2.1 Xinchao Media: Application of Low-Carbon Elevator Smart Screen in Urban Warning Information Broadcasting

1. Background

According to the "Implementation Measures of the People's Republic of China Emergency Response Law in Shanghai" and the "Shanghai Management Measures for the Release of Emergency Warning Information," it is required to use information dissemination platforms to release emergency warning information. This is to ensure urban safety, mitigate the impact of emergency events, and comply with national and Shanghai's energy-saving and low-carbon policies.

Elevators are essential places for urban residents, and the existing elevator smart screens are utilized to manage emergency information in a classified manner, provide hierarchical warnings, and share information across platforms. Through the elevator smart screen, the classification, grading, and platform sharing of emergency warning information are achieved. The Emergency Warning Release Center and the Xinchao Media Operations Control Room are interconnected through interface data. The warning information is generated into encrypted data files and pushed to the Xinchao Media. After verifying the information, the control room completes the information broadcast. Once online, various severe weather warning messages are broadcasted on the Xinchao Media smart screens.

The elevator smart screen uses low-energy screens produced by BOE, resulting in a reduction of 2,500 tons of carbon dioxide emissions per year for nearly 60,000 elevators in Shanghai, with a 25% decrease in energy consumption.

2. Main Contents

Collaboration with Relevant Departments

a. City Emergency Management Bureau: Coordinates various departments for warning release work.

b. Various Warning Management Units: Prepares corresponding warning information based on the possible development situation of the event and the warning level.

c. City Emergency Warning Information Release Center: Sends warning information to the Xinchao Media within 5 minutes through the system.

d. Xinchao Media Group: Assists in establishing a "green channel" to ensure the first-time release of warning information to the public according to publishing requirements.

Release Procedure

a. Early Notification: The City Warning Release Center contacts the duty personnel at the Xinchao Media Operations Control Room in advance, especially when issuing non-meteorological emergency warnings.

b. Warning Production: Various warning management units produce warning information according to relevant standards and send it to the Warning Release Center via the system, fax, email, including information upgrades or updates.

c. Scrolling Marquee Requirements: The City Warning Release Center completes the "Xinchao Media Emergency Event Information Release Request Form" and sends it to the Xinchao Media Operations Control Room after approval. The request is for broadcasting warning information to the public through scrolling marquees or icons.

d. Broadcasting: Upon receiving warning information, the Xinchao Media Operations Control Room promptly broadcasts the warning information to the public through scrolling marquees or icons as per the request form.

e. Warning Relief: The warning management unit sends relief content to the City Warning Release Center, and the center releases the relief information. The Xinchao Media Operations Control Room publishes relief information or stops scrolling marquees (icons) as per the request form.

f. Information Transmission: The City Warning Release Center and the Xinchao Media Operations Control Room are interconnected through interface data. When there is a warning, encrypted data files are generated and sent to the control room, which verifies and completes the information broadcast.

g. Information Feedback: After publishing, the Xinchao Media provides feedback to the City Warning Release Center through data files, including information on release points, quantity, time taken for release, published videos, or screenshots.

h. Monitoring: The City Warning Release Center monitoring station is responsible for monitoring the Xinchao Media's warning information release status, promptly communicating and addressing any issues during the release.

Figure 4-17: Smart Warning Source: Xinchao Media

3. Summary and Reflection

The case involves the use of emergency warning information on elevator smart screens, incorporating both text and icons. The use of icons adheres to agreed-upon standards or industry norms, ensuring that there is no additional learning burden on citizens. Other emergency management departments in different cities are currently in the process of coordination. Through the application of elevator smart screen technology, the case serves as a demonstration for city severe weather warnings and disaster reduction, without contributing to increased carbon emissions. The City Warning Release Center effectively monitors the information release by the Xinchao Media and maintains timely communication to address any arising issues.

This case has inspired Xinchao Media to initiate a public welfare campaign for urban net-zero carbon transformation, supporting well-known brands in the national net-zero carbon field. Additionally, there are plans to establish a nationwide screen energy consumption monitoring system and collaborate with the China Elevator Association to formulate technical requirements standards for elevator displays, including energy consumption standards.

4.2.2 BOE Technology Group Co., Ltd.: Application of Smart Windows in Urban Carbon Reduction

1. Background

With global warming, the energy consumption of air conditioning in urban areas is gradually increasing, accounting for a larger proportion of the total building energy consumption. The carbon emissions generated by air conditioning are also on the rise, and the impact of the urban heat island effect is becoming more severe. To combat climate change and reduce urban carbon emissions, the upgrading of people centered building materials and technologies in smart energy efficiency has become an inevitable choice for cities to transition towards net-zero carbon.

2. Main Contents

BOE Smart Window Digital Innovation Solution optimizes the utilization of natural light, reduces the energy consumption of air conditioning, thereby lowering energy consumption and carbon emissions, and improving the energy efficiency of buildings. The digital innovation solution for smart windows adopts a carbon reduction mode from production to application. The manufacturing process in the production end uses a green factory with recycled water circulation and photovoltaic power generation. In the application end, the solution controls the deflection of liquid crystals to adjust the light transmittance of windows, allowing buildings to maximize the use of natural light when needed and reduce light entry when not required. This intelligent adjustment can be achieved through dynamic control of the building's peripheral structure or a more advanced digital control system. BOE's Smart Window Digital Innovation Solution provides services for public buildings, office spaces, and shopping malls in four major aspects: natural shading, building energy conservation, privacy protection, and smart IoT.

a. Natural Shading: Smart windows can effectively block direct sunlight by adjusting the glass's transmittance, preventing direct sunlight from irritating the eyes and reducing the glare effect of strong light.

b. Building Energy Conservation: Smart windows control the solar energy entering the building by adjusting the glass's transmittance, thereby reducing the use of air conditioning and achieving energy-saving effects. When installed in buildings, they can block about 70% of sunlight, effectively lowering indoor temperatures and reducing energy consumption. Additionally, with its energy-efficient design, such as low drive voltage and low power consumption, it further reduces energy consumption.

c. Privacy Protection: Smart windows can continuously adjust the glass's transmittance, making the glass transparent when needed and turning it into a dark state when not needed. This intelligent adjustment effectively protects the privacy of indoor spaces. It also features zone dimming modes, similar to blinds, providing homeowners with a more intelligent and convenient dimming option.

d. Smart IoT: Smart windows can be combined with Internet of Things (IoT) technology to achieve linkage with other smart devices or sensors. For example, when the indoor temperature is too high, smart windows can automatically adjust the glass's transmittance to lower the indoor temperature. When there is insufficient indoor lighting, the system can automatically adjust the glass's transmittance to provide adequate indoor lighting. Moreover, smart windows can be remotely controlled via a mobile app, allowing users convenient operation.

2. Relevance to SDGs

The BOE Intelligent Window Digital Innovation Solution is not only applied in the field of construction but also extends to passenger car side windows, skylights, and rail transportation. It significantly reduces energy consumption in urban construction and rail transportation, providing urban workers with a more comfortable and intelligent working environment. This also contributes to achieving the United Nations Sustainable Development Goals (SDGs), including SDG12 (Ensuring sustainable consumption and production patterns), SDG9.2 (Promoting inclusive and sustainable industrialization), and SDG11 (make cities and human settlements inclusive, safe, resilient, and sustainable).

Figure 4-18: BOE Smart Windows showcased at the Second UN-Habitat Assembly Source: BOE

4.2.3 BYD: Application of New Medium and Low Volume Rail Transit System in Urban Carbon Reduction

1. Background

Global urbanization continues to rise, reaching 56% in 2021, and is expected to increase to 68% by 2050. This has led to worsening traffic congestion, with the global number of cars reaching 1.446 billion by the end of 2022. In the 30 most congested cities, people spend an average of 45% of their time in traffic jams every day. Pollution from transportation, such as motor vehicles, has become a major contributor to urban air pollution, causing approximately 7 million premature deaths worldwide each year.

Despite the global consensus on promoting diverse green transportation options, the high cost of subway construction and the heavy operational burden pose significant obstacles to the development of large-capacity rail transit. Taking China as an example, the cost of building a subway is 8-10 billion yuan per kilometer, and the total life-cycle operating cost is 2-3 times the construction investment, with an average operating revenue-to-expense ratio of only 53.38%.

Main Contents

The BYD SkyRail is a new type of medium and low-capacity rail transit system developed by BYD over many years, adhering to the principles of scientific planning, technological innovation, high integration, environmental friendliness, and intelligent wisdom. It aims to create an environmentally friendly, safe, convenient, comfortable, humanistic, and economically viable three-dimensional transportation solution.

a. Scientific Planning: with elevated independent rights-of-way, rubber tire operation, zero-distance boarding, maximum slope of 12%, minimum turning radius of 15m, penetrating into communities, and maximizing passenger convenience.

b. Technological Innovation: Integration of automobiles and rail transit, application of core technologies of new energy vehicles such as blade batteries, permanent magnet synchronous motors, intelligent electronic control, leading technologies such as vehicle-bridge coupling, intelligent power supply management systems, and fully automatic operation systems.

c. High Integration: Adhering to the design concept of "addition on buses." Compact and lightweight, assembly-type stations, deep integration, unified interfaces, a 93% reduction in equipment room area, a control center requiring only 3 people to complete full-line scheduling, construction costs only 1/10 of the subway, and operating costs half of the tram.

d. Environmental Friendliness: Green, low-carbon, and energy-efficient, using renewable steel, blade battery drive, zero pollution emissions throughout the process, rubber tire operation with noise below 68dB, and the intelligent energy management system reducing operating energy costs.

e. Intelligent Wisdom: Unmanned or lightly manned operation management, fully automatic unmanned driving, intelligent dispatching, intelligent operation and maintenance, humanized passenger service system. In the operation of Chongqing Bishan, only 2 people/km are required, saving more than 90% of labor costs.

Figure 4-19: Shenzhen Pingshan Skyrail
Source: BYD

2. Relevance to SDGs

BYD's medium and low-volume rail transit is based on technological innovation and closely aligns with the United Nations Sustainable Development Goals, including "Sustainable Cities and Communities," "Responsible Consumption and Production," "Industry, Innovation, and Infrastructure," "Affordable and Clean Energy," and "Climate Action." It aims to improve the quality of green travel for urban residents, ensure the well-being along transit lines, and serve vulnerable groups. It has achieved short-term economic benefits, external positive effects, and social acceptance. In the long term, it promotes industry innovation, facilitates efficient urban transportation, and guides a low-carbon lifestyle.

3. Achievements

Currently, BYD's medium and low-volume transit solutions have been applied in various cities, including Yinchuan, Ningxia, Bishan in Chongqing, Pingshan in Shenzhen, Dawangshan in Changsha, High-tech Zone in Xi'an, Guiyang, and São Paulo, Brazil. The direct investment exceeds 10 billion yuan, and its safety, reliability, and cost-effectiveness have been fully validated on operational routes.

Long-term Achievements

a. Promoting Industry Innovation and Development: BYD's medium and low-volume rail transit introduces a new technological system, design philosophy, and operational model into the urban rail industry. It contributes to industry innovation and diversity, providing new choices for urban public transportation.

b. Promoting Urban Economic and Industrial Chain Development: The construction of BYD's medium and low-volume rail transit system guides the development of surrounding land, promotes the rational layout and utilization of areas along the route, and contributes to the development of industries such as design, research and development, equipment manufacturing, construction, and operation management.

c. Facilitating the Construction of an Efficient Urban Transportation System: BYD's medium and low-volume rail transit, with its elevated independent road rights, compact and lightweight design, and high flexibility and efficiency, complements high-capacity subways. It helps build a coordinated rail transit system of large, medium, and small capacities, improving the operational efficiency of the urban rail network and facilitating the construction of an efficient urban transportation system.

d. Guiding a New Low-carbon Lifestyle: BYD advocates for the creation of a green transportation system, using electric vehicles to combat pollution and "Yunba" to address traffic congestion. The medium and low-volume rail transit system is seamlessly integrated into urban environments, utilizing spaces under bridges to create slow traffic systems. It aims to build public leisure spaces where people and nature coexist harmoniously, optimizing commuting, work, life, and entertainment. This approach enhances the quality of life and promotes a new green lifestyle.

4.2.4 DiDi: Digital Mobility Platform Facilitating Urban Net Zero Carbon Transition

1. Background

According to statistics from the International Energy Agency, global carbon dioxide emissions in the transportation sector have been increasing annually, making transportation the second-largest emitter, accounting for 25% of global emissions. Road transportation, in particular, is a significant source, contributing to 75% of emissions within the transportation sector. In China, the current carbon emissions from the transportation sector represent over 10% of the national total, with road transportation constituting approximately 80%, and the emissions continue to grow. In summary, the transformation of urban transportation towards zero carbon has significant potential for energy conservation and emission reduction, with broad-ranging impacts. It is a crucial battleground for advancing efforts in the "dual carbon" goal.

2. Main Contents

DiDi's innovative solution on the digital mobility platform is committed to promoting the electrification of urban transportation, efficient resource utilization, a low-carbon travel structure, green power sources, and an intelligent transportation system. It aims to facilitate the net-zero carbon transformation of urban transportation:

a. Scientific Accounting: DiDi utilizes the "Changqing" carbon management tool to dynamically calculate the carbon emissions of the platform's travel ecosystem. It focuses on green indicators, identifies emission reduction opportunities, and solidifies the foundation for low-carbon development.

b. Full Lifecycle Management: DiDi Qingju is dedicated to the low-emission, low-consumption, and efficient development of shared two-wheeled vehicles throughout their entire lifecycle. This initiative propels the joint green development of the industry chain, encouraging a greener and more low carbon lifestyle.

c. Carbon Inclusive Promotion: Through digital means, DiDi introduces the "Carbon Credits" product, incentivizing passengers to choose low-carbon travel methods. Simultaneously, it launches a carpooling environmental incentive program to reward drivers for green miles. On the energy side, the "Low-Carbon Homestead" product guides users to charge their vehicles during off-peak hours, contributing to the "peak-shaving and valley-filling" strategy for the power grid.

d. Comprehensive Strategy: DiDi proposes the "1+3" model, leveraging digital mobility to support carbon neutrality. This model aims to promote a broader range of energy conservation and emission reduction, extending the spill-over effects of zero-carbon transformation:

- **Customization of Transport Vehicles:** In collaboration with BYD, DiDi customizes ride-hailing vehicles, such as D1, to achieve mutual promotion and enhance energy consumption efficiency.

- **Co-building and Sharing Infrastructure:** Utilizing the "Xiaoju Energy" platform, DiDi optimizes the layout of urban charging infrastructure through intelligent technology, improving facility utilization and promoting the development and popularization of new energy vehicles in cities.

- **Technological Empowerment of Green Transportation Systems:** DiDi's development of the "Smart Traffic Control System" utilizes data analysis to coordinate signal systems, reducing congestion and delay time at intersections, effectively decreasing carbon dioxide emissions.

e. Global Sustainable Transportation Impact: Since initiating its international strategy in 2018, DiDi has expanded its services to cover 14 countries, providing diverse services and receiving widespread acclaim in local markets. In Brazil, DiDi leads the "Brazil Sustainable Mobility Alliance" and collaborates with local businesses to promote the adoption of new energy vehicles and electrification of ride-hailing cars. The plan aims to increase the penetration rate of new energy vehicles from 2% to 10% by 2025 and build 10,000 new public charging stations. DiDi will introduce the world's first customized ride-hailing electric vehicle, the DiDi D1, while also offering secure online payment services to promote the widespread use of mobile payments in Brazil.

3. Summary and Reflection

DiDi's digital mobility platform innovation project is based on efficient resource utilization, leveraging big data and intelligent algorithms to enhance urban transportation operational efficiency and digital service capabilities. Through innovative models, it leads low-carbon travel, drives the collaborative advancement of upstream and downstream stakeholders toward green net-zero carbon transforma-

Figure 4-20: Didi Digital Carbon Inclusion Action Source: DiDi

Figure 4-21: Didi Supports Digitalization and Green Development in Brazil Source: DiDi

tion, and generates a “spillover effect” in carbon reduction. It plays a leading and driving role in urban transportation’s zero-carbon transformation. In 2022, DiDi, by providing green mobility services, collectively contributed to reducing carbon dioxide emissions by 3.38 million tons in Chinese cities. In the future, with “Changqing” as the data foundation and the “1+3” model as the directional guide, DiDi aims to expand carbon-inclusive actions, develop more green mobility products, internalize energy conservation and emission reduction as a driving force for corporate development, and synergize with China’s carbon peak and carbon neutrality strategic pathways.

In operations, DiDi faced challenges in scientifically quantifying emissions and continuously explored carbon emission accounting for urban travel and shared transportation ecosystems. Collaborating with the Research Institute of the Ministry of Transport, DiDi jointly developed a carbon management tool. In response to urban variations and business line characteristics, the “Changqing” tool dynamically accounts for indicators in different cities, provinces, and business lines, providing fundamental data and logical support for the execution of carbon-inclusive products.

4.2.5 Midea Building Technology: Application of Comprehensive Carbon Reduction Governance Solution in Digital Transformation of Industrial Parks

1. Background

Industrial parks are an indispensable core component of urban socio-economic development and a key carrier for the strategies of new urbanization and building a manufacturing powerhouse. However, the amount of carbon emissions released by industrial parks account for 31% of that of national total, making it a crucial goal to achieve “dual-carbon” goals and carbon reduction. With the expected growth in energy demand for future industrial parks, addressing the “dual-carbon” goals during economic development becomes a necessary choice and ultimate objective for the upgrading of industrial parks.

Facing the five major challenges of carbon accounting, planning, implementation, operation, and performance in industrial park carbon management, Midea Building Technology, based on the comprehensive digital capabilities of iBUILDING, utilizes the IoT platform of Cloud-edge collaboration. It provides a comprehensive solution for full-chain carbon management through digital twinning, AI energy optimization, and knowledge graphs. Starting from the dimensions of time, technology, and customers, it implements carbon reduction measures in a graded and layered manner, offering customers a full lifecycle of green and low-carbon services.

2. Main Contents

In terms of technological innovation, Midea Building Technology has adopted the steps of carbon accounting, carbon analysis, carbon assessment, and carbon reduction, comprehensively advancing the implementation of energy conservation and carbon reduction. In the time dimension, the company carries out phased energy conservation and carbon reduction work for industrial park buildings from planning and design to abandonment. This includes proactive equipment selection, substitution with renewable energy sources, green construction management, lean management, predictive maintenance, and more.

Recognizing the differences in various types of industrial parks, such as manufacturing-oriented, commercial office-oriented, and mixed-use parks, Midea Building Technology has proposed differentiated countermeasures like carbon dashboards, carbon consulting, organizational carbon, product carbon, carbon credits, etc. This is to support the digital transformation of carbon management in industrial parks, taking into account the variations in different types of industrial parks.

Innovations

a. A Platform that Covers the Green and Low-carbon Needs of Multiple Users, All Scenarios, and the En-

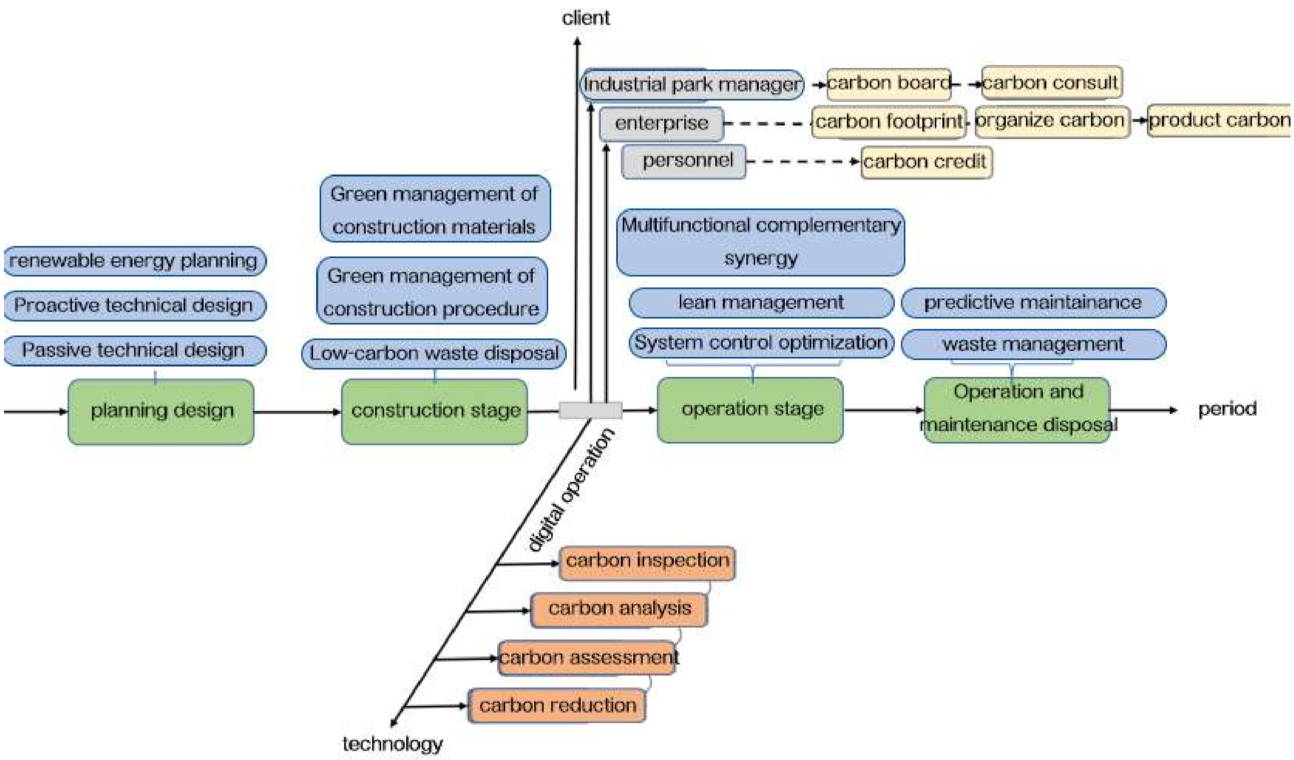


Figure 4-22: Comprehensive Governance project Diagram for Full-Chain, Multi-Dimensional, Graded Carbon Reduction
Source: Midea Building Technology

tire Life Cycle.

b. The Integration of Virtual and Real-world Intelligent: digital twins, combining data with domain knowledge. This involves using data-driven methods for rational energy allocation and algorithm-driven optimization management.

c. Achieving End-to-End Digitization: addressing carbon reduction issues in different industrial park formats through modular software solutions.

3. Relevance to SDGs

The Midea comprehensive governance solution for carbon reduction across the entire chain is closely related to the United Nations Sustainable Development Goals (SDGs), including SDG7 (Promote clean energy), SDG9 (Promote industry, innovation, and infrastructure), SDG11 (Sustainable cities and communities), SDG12 (Ensure sustainable consumption and production), and SDG13 (Climate action). This digital innovation solution can assist self-sustaining park enterprises in more effectively managing energy structures, improving system efficiency, and reducing the complexity of carbon trading. It supports manufacturing industries in enhancing process automation and optimizing energy usage efficiency. It helps leasing and commercial enterprises understand energy trends, reducing carbon emissions. It enhances the fine management capability of park properties, lowering operational difficulties. The carbon credit mini-program stimulates employees to adopt low-carbon and carbon-reducing lifestyles and work practices.

4. Summary and Reflection

The Midea comprehensive governance solution for carbon reduction across the entire chain generates environmental, economic, and social benefits. On the environmental front, it innovatively reduces carbon emissions and electricity expenses through digital innovation. Economically, it enhances energy utilization efficiency, driving revenue from carbon trading. In terms of long-term social benefits, the solution can expand to more links in the supply chain and serve as a practical reference for replication and promotion in different application scenarios.

Follow-up measures and supervision evaluations mainly focus on carbon calculation and management, including :

a. Strengthening carbon footprint investigation capabilities on the digital platform to support the calculation and certification of product and activity carbon;

b. Improving the accuracy of carbon account monitoring, establishing continuous tracking and governance mechanisms to ensure the clarity and supervision of improvement tasks in terms of goals, timelines, and assessments.

In the research and development as well as the operation and maintenance phases, challenges were encountered, including the diversification of business formats and the traceability of system data sources.

a. Addressing the diversity of requirements from different business format parks, requiring the system platform to have flexibility in configuration to cover various customized demands.

b. Data source integration and traceability, necessitating the management of data quality to ensure real-time matching and accuracy of the data.

Figure 4-23: Midea Industrial Park Carbon Emissions

Source: Midea Building Technology

Recommendations

This chapter will summarize the entire report in four subsections: “The Urgency of Global Actions to Address Climate Change,” “Commitment to Developing Digital Technology to Drive Urban Net-Zero Carbon Transition,” “Chinese Urban Actions and Global Collaboration,” and “Global Initiatives for Urban Digital Net-Zero Carbon Actions.”

05

Chapter 5

Summary

In September 2023, during the high-level session of the General Assembly, United Nations Secretary-General Antonio Guterres convened the Climate Ambition Summit, calling on governments, businesses, cities and regions, civil society, and financial leaders to contribute "reliable, serious, and novel climate actions and nature-based solutions to accelerate efforts to address the urgent climate crisis." This summit marks a significant political milestone, indicating a global shared willingness to expedite and expand a just transition towards a more equitable, renewable energy-based, and climate-resilient global economy. Antonio Guterres emphasized, " Now must be the time for ambition and action. The world is watching – and the planet can't wait."

Climate change, as one of the three major global crises, has profound impacts globally in ecological, socio-economic, and health safety aspects. China, being the world's largest developing country, is significantly affected by climate change, and global actions to address climate change are urgent. The Chinese government, in 2020, set the "dual-carbon" goals: carbon peaking by 2030 and carbon neutrality by 2060. It has implemented policies across various sectors and actively collaborated globally to tackle the challenges of net-zero carbon.

Simultaneously, global digital technology is rapidly advancing, bringing new opportunities for development across various industries. The application of digital technology in environmental governance requires global attention, as it is helping accelerate urban net-zero carbon transition and playing an increasingly crucial role. Achieving urban net-zero carbon transition requires actions across multiple dimensions, including building and housing, water usage, transportation, waste recycling, energy, and carbon management. The development of digital technology enables the smart and efficient operation of these dimensions. Digital innovation technologies such as the Internet of Things (IoT), big data, cloud computing, and artificial intelligence become key pathways to achieve urban net-zero carbon goals. Through a three-step model of "capturing carbon data – formulating carbon strategies – implementing intelligent carbon actions," a positive feedback loop in urban carbon management can be established, promoting digitalization, greenization, and sustainable development of cities. Furthermore, the application of digital technology still has significant potential for further development and exploration in the field of environmental governance.

China actively responds to global carbon reduction goals, leveraging digital means to implement a series of carbon reduction measures. It has formulated more specific and efficient implementation paths across policy, finance, industry, and technology sectors. Chinese cities, along with global cities, are advancing towards urban net-zero carbon transition goals, propelling cities towards a more sustainable and low-carbon future.

5.1 Urgency of Global Actions on Climate Change

Climate change is progressively intensifying its impact on the global living environment. Currently, the Earth's temperature is approximately 1.1°C higher than at the end of the 19th century, and emissions continue to rise. This has led to significant threats to human existence, including rising sea levels, warming oceans, loss of freshwater reserves, degradation of soil and water resources, outbreaks of diseases and agricultural crises, population migrations, regional conflicts, increased and expanded natural disasters, among other critical effects. For instance, the increasing frequency of high water levels in the water city of Venice could, in the worst-case scenario, lead to its disappearance beneath the sea by 2100. In drought-stricken regions like Kenya in Africa, climate-induced food production declines have resulted in many losing their livelihoods, food, and sources of income. In Sudan, desertification and drought-induced conflicts have displaced large numbers of local populations.

If climate change continues to worsen, it will cause irreversible environmental damage, economic decline, social disorder, and even the disappearance of human civilization. The Intergovernmental Panel on Climate Change (IPCC) issued a significant warning in 2018, stating that global warming must be limited to 1.5 degrees Celsius, or the Earth will face catastrophic climate destruction after 2030. Addressing climate change has become the most significant and urgent challenge in achieving the United Nations Sustainable Development Goals.

The 2030 Agenda for Sustainable Development, adopted by the United Nations in 2015, emphasizes the importance of building inclusive, safe, resilient, and sustainable cities and human settlements (Goal 11), taking urgent action to combat climate change and its impacts (Goal 13), and strengthening the means of implementation to revitalize the global partnership for sustainable development (Goal 17). These goals highlight the critical role of global cities in addressing climate change.

Figure 5-1: 2023 United Nations Climate Ambition Summit Source: DownToEarth.org

The New Urban Agenda, released by the United Nations in 2016, acknowledges the relationship between city centers and climate change. It notes that city centers worldwide, especially in developing countries, are particularly vulnerable to adverse impacts of climate change.

In the 27th Conference of the Parties to the United Nations Framework Convention on Climate Change (COP27) in 2022, the first ministerial meeting on urbanization and climate change was held. COP27 also initiated the "Building Sustainable and Resilient Cities for the Next Generation" (SURGe) initiative, envisioning the establishment of effective multilevel governance to transform cities into healthy, sustainable, just, inclusive, and resilient urban centers.

In March 2023, the Intergovernmental Panel on Climate Change (IPCC) released the AR6 Synthesis Report: Climate Change 2023, which pointed out adverse impacts of observed climate change on human health, livelihoods, and critical infrastructure in urban areas, exacerbating extreme heat events.

In June 2023, the second United Nations Human Settlements Assembly convened in Nairobi, aiming to advance the realization of the United Nations Sustainable Development Goals. The assembly outlined five key action areas, including universal access to adequate housing, urban climate action and environmental protection, urban recovery from crises, localization and multilevel governance of sustainable development goals, and prosperity and finance. It called on all stakeholders to take active actions and contribute to the implementation of the United Nations Sustainable Development Goals and the New Urban Agenda. The assembly passed a resolution titled "Strengthening the Connection between Urbanization and Climate Change," further highlighting the importance of sustainable urban development in addressing climate change.

In summary, cities play a crucial role in addressing climate change as major sources of greenhouse gas emissions and key areas for climate change mitigation. The United Nations and its related organizations have consistently emphasized the urgency of sustainable urban development and mitigating climate change. However, global efforts by cities to address climate change lag significantly behind the impacts it brings. Urgent global action to address climate change is imperative.

Figure 5-2: United Nations climate action: the road to "net zero" emissions

Source: https://www.un.org/sites/un2.un.org/files/2021/12/cutting_emissions.jpeg.jpg

5.2 Leveraging Digital Technology in Urban Net-Zero Carbon Transition

Cities are home to the majority of the global population and serve as hubs for human activities and carbon emissions. However, they are also centers for the development and application of innovative technologies. Despite the significant role of digital technology in driving urbanization and various industries, the main tracks of digital technology development have not yet fully covered global environmental governance. Therefore, exploring innovative paths for digital technology and guiding its development to effectively address the challenges of climate change are potential solutions and even necessary choices for the fragmented actions, lack of global coordination, digital divide, data security and privacy concerns, and high carbon emissions associated with digital infrastructure encountered by global cities in the current response process. Planning for key actions, cross-border investment and cooperation, improving policy support, mobilizing social and technological resources, and considering the sustainability of digital systems will become key topics in leveraging digital technology in the urban net-zero carbon transition.

Achieving urban net-zero carbon transition involves

Figure 5-3: AR6 Synthesis Report: Climate Change 2023 Source: IPCC

Figure 5-4: The second United Nations Human Settlements Assembly Source: ChinaDaily.com

key actions in areas such as buildings and housing, energy, water use, transportation, waste recycling, and carbon management. Therefore, more efficient urban planning becomes crucial. Efficient urban planning can not only reduce carbon emissions and enhance urban sustainability across various dimensions of city management, infrastructure, land use, and community development but also assist cities in mastering carbon data, formulating carbon strategies, and implementing smart carbon actions.

Although the process of net-zero carbon transition implies inevitable additional costs, the application of digital technology and digital management methods can minimize the transition costs or rationalize the investment in the process through sustainable profitability. At the same time, this opens up opportunities for sustainable economic growth. Digital transition has started to deeply develop in various industries, and the technology is relatively mature. However, its application in environmental-related fields and urban net-zero carbon transition is still relatively limited. The key challenge is to widely and deeply apply the results of digital technology development to the entire process of urban net-zero carbon production systems, transforming the demands of urban net-zero carbon into opportunities for sustainable urban economic growth.

In summary, digital technology is a key pathway to achieving urban net-zero carbon goals, providing powerful tools for various aspects of urban development and promoting sustainable development. However, the carbon footprint of digital systems itself needs to be valued and effectively managed. The continuous innovation and integration of digital technology will continue to drive cities towards a cleaner, smarter, and more sustainable future.

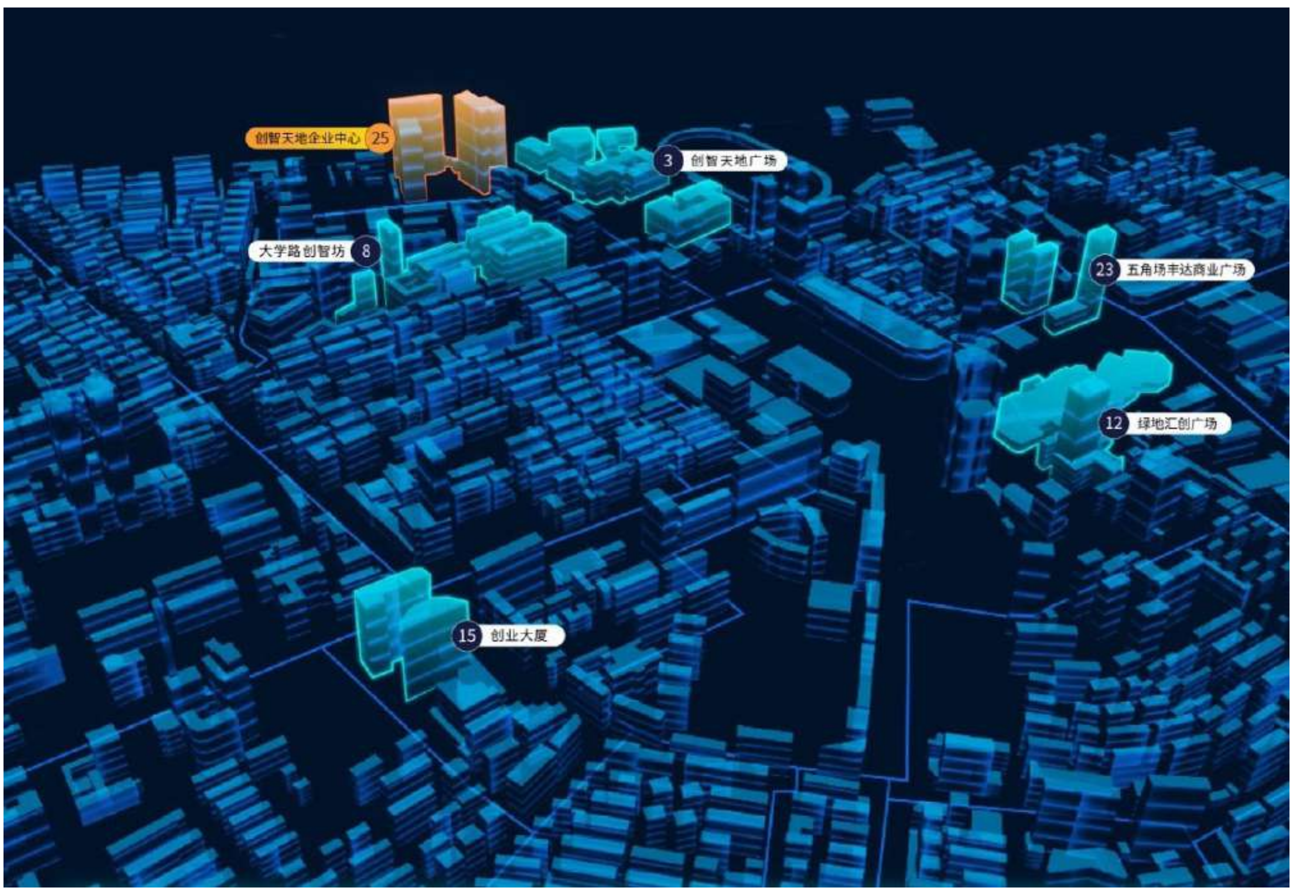


Figure 5-5: Digital city solutions
Source: AECOM

5.2.1 Achieving Urban Net-Zero Carbon Transition as a Key Action

Achieving urban net-zero carbon transition is a complex task that spans multiple dimensions of cities. It requires action across various aspects of city operations, including buildings and housing, urban water, urban mobility, urban waste and circulation, urban energy, and carbon management. Therefore, coordinating and planning urban development across these dimensions becomes a necessary means of comprehensive management for multiple key transition points. Precise and efficient urban planning needs to consider multiple aspects of urban net-zero carbon, balance economic, social, and environmental benefits, and use digital innovation technology to enhance the efficiency of urban planning itself, facilitating urban net-zero carbon transition.

Building & Housing: Technologies such as big data, artificial intelligence (AI), Building Information Modeling (BIM), smart sensors, and digital twins can empower energy management scenarios during the design, construction, and operation phases of buildings. The Internet of Things (IoT) and data processing can empower intelligent heating and cooling supply for buildings.

Urban Water: Technologies like digital twins, sensors, IoT, big data, AI, and algorithms can be applied to optimize overall planning of water resource utilization, water flow monitoring, predicting water usage, optimizing reservoir operations, and other water resource allocation scenarios. Deep neural networks, GIS, sensors, and other technologies can assist in the operation and maintenance of water supply networks.

Urban Mobility: Technologies such as sensors, wireless communication, big data, and AI algorithms help with intelligent traffic management, improving transportation efficiency. Remote sensing, GIS, radio frequency identification (RFID), wireless communication, and other technologies help in locating intelligent charging facilities, optimizing charging status, and scenarios like vehicle-to-grid (V2G).

Urban Waste and Circularity: Data sharing, databases, and IoT technology help establish incentive mechanisms for waste recycling. AI algorithms, smart sensors, IoT, and other technologies assist in waste classification, on-site waste classification, and optimizing waste collection routes.

Urban Energy: Utilizing technologies like AI, IoT, big data, and cloud computing to establish and maintain smart grids, using smart controllers, network technology, blockchain, algorithms, etc., to establish an energy internet, and optimizing energy structures.

Carbon Management: Technologies such as drones, blockchain, data analysis, deep learning, etc., can be used for carbon accounting, carbon trading, and carbon financing, helping achieve a comprehensive carbon management system.

In summary, urban net-zero carbon transition is a multidimensional task that requires the support of digital innovation technology in various dimensions of urban planning. From building, water use, transportation, waste management, energy to carbon management, each field can leverage technologies like big data, AI, IoT, sensors, etc., to improve efficiency, reduce carbon emissions, and achieve a more sustainable and environmentally friendly city. At the same time, it is crucial to not overlook the focus on the digital transition and upgrade of urban planning itself, mobilizing more complex and diverse technological resources. The integrated application of these technologies will contribute to achieving the net-zero carbon goals of cities, creating more livable urban environments.

Figure 5-6: Building Information Modelling (BIM) technology Source: BIM

5.2.2 Digital Technology as a Key Path to Achieving Urban Net-Zero Carbon Goals

Urban net-zero carbonization and its roadmap are complex system engineering and a dynamic solution that constantly evolves. Digital innovation technologies represented by the Internet of Things (IoT), big data, cloud computing, and artificial intelligence (AI) are the key path to achieving urban net-zero carbon goals. Through a three-step model of "***mastering carbon data-formulating carbon strategies-smart carbon actions***," a positive feedback loop of urban carbon management is established, promoting urban digitization, greening, and sustainable development.

a. Mstering Carbon Data: As primary participants in climate change mitigation, cities require a specific mechanism for collecting and accounting for carbon emissions due to the dispersed nature of emissions driven by urban demands. Digitalization is needed for carbon footprint collection, clarifying both production and consumption-side carbon footprints. System efficiency improvement can be achieved through AI technologies, multi-objective optimization, greedy algorithms, genetic algorithms, and other optimization strategies to achieve energy savings and carbon reduction. This step involves establishing a data foundation, building a "dual carbon" brain for the city, and constructing greener data centers.

b. Formulating Carbon Strategies: China aims to integrate a systemic approach throughout the entire process of "dual carbon" work, establishing strategies and policies to address climate change systematically. Digital technology supports urban carbon models, feedback loop management, and has decision-making significance for formulating net-zero carbon strategies. The first step is to construct a positive feedback loop of carbon management involving "planning, implementation, accounting, and analysis." Secondly, it is crucial to formulate strategies based on local conditions, adapt to the scale of "carbon," and coordinate national efforts to form a systemic force for carbon reduction. Thirdly, a balance is needed between development and emission reduction, overall and local considerations, long-term and short-term goals, and the relationship between government and the market.

c. Smart Carbon Actions: Data can enhance urban efficiency by optimizing energy efficiency through four modes: supply-side optimization, near-demand-side optimization, demand-side optimization, and supply-demand coordination. This can be achieved by optimizing traffic management and electrifying the public transportation system to enhance urban traffic efficiency. Additionally, data can enhance urban resilience through four aspects: energy security, transportation resilience, building resilience to climate change, and water system resilience.

Figure 5-7: Shenzhen's "Dual Carbon Brain": The First Carbon Emission Monitoring and Management System for Buildings in China

Source: sz.gov.cn

As a hub for industrial and economic activities, cities are dynamic in terms of carbon neutrality. Urban carbon neutrality is not a one-time state but a dynamic balance between carbon sources and carbon sinks. The support of digital technology enables cities to dynamically achieve net-zero carbonization by addressing various factors such as the effectiveness and cost of energy-saving and carbon reduction technologies, as well as factors like negative carbon technologies and forest carbon sink levels.

5.2.3 Digital Technology Facilitating the Carbon Reduction Tools in Industries

Digital technology plays a crucial role in helping various industries achieve net-zero carbon goals, primarily through three aspects: ***digitized information, digitized processes, and digitized products***.

a. Digitized Information

- **Data Collection and Analysis:** Digital technology assists cities in collecting large-scale environmental data, including energy usage, traffic flow, and pollution levels. This data can be used to precisely analyze the city's carbon emission sources, aiding in the formulation of accurate carbon reduction strategies.

- **Smart Sensors and Monitoring Systems:** Digital technology enables cities to deploy smart sensors and monitoring systems, continuously tracking energy consumption, air quality, and traffic flow. This information can be used to adjust the city's equipment and resource usage in real-time, thereby reducing carbon emissions.

- **Simulation and Predictive Analysis:** Digital technology allows cities to build models and simulate scenarios to predict the effectiveness of various carbon reduction measures. This helps urban planners choose the most efficient strategies to minimize carbon emissions.

b. Digitized Processes

- **Smart Urban Planning:** Digital technology assists urban planners in designing more carbon-efficient city layouts, reducing commuting distances, and optimizing green spaces and public transportation systems.

- **Energy Efficiency:** Digitized processes help city managers optimize energy usage, including energy-efficient buildings, automatic adjustments to lighting systems, and smart power grid management.

- **Supply Chain Optimization:** Digitized processes can enhance the sustainability of supply chains, reducing energy waste in transportation and warehousing and decreasing the carbon footprint.

c. Digitized Products

- **Renewable Energy:** Digital technology helps improve the efficiency and production of renewable energy sources such as solar and wind power. Digital monitoring systems ensure the maximum utilization of these resources, reducing carbon emissions.

- **Smart Buildings:** Digitized products include smart building technologies, such as intelligent lighting, HVAC systems, and energy management systems, significantly reducing a building's energy consumption.

- **Electric Transportation:** Digital technology drives the development of electric vehicles and transportation. The use of these vehicles can substantially lower carbon emissions, especially when charged with renewable energy.

By leveraging data analysis in digitized information, optimizing processes through digitization, and applying digitized products, cities can more effectively monitor and reduce carbon emissions. To better address climate change, urban net-zero carbon transition is imperative. However, the affordability of the information, process, and product aspects involved in digital transition requires practical and thorough consideration. Firstly, the cost-benefit balance of digital transition needs to be reasonable and affordable, favoring the development, promotion, and application of digital transition solutions. Secondly, from a long-term perspective, digital transition must bring long-term economic and social benefits. By accelerating the flow and exchange of elements through digital technology networks, the establishment of digital carbon sink markets and carbon trading systems, for example, can further exchange future benefits for current support. In summary, digital technology is helping various industries develop affordable carbon reduction tools in multiple aspects, encouraging more cities to reduce carbon emissions for a more sustainable urban and social development.

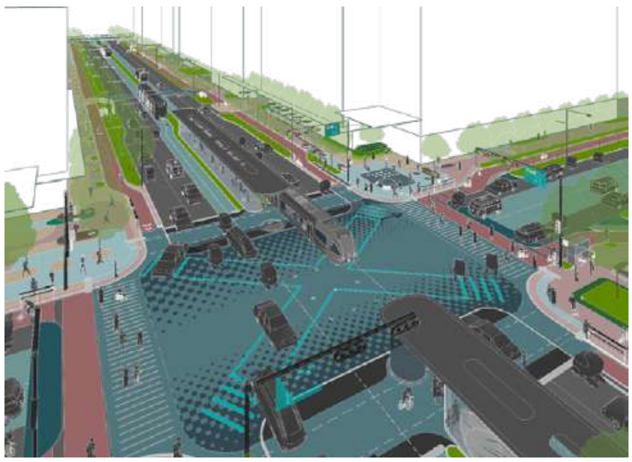


Figure 5-8: Smarter urban planning
Source: AECOM

5.2.4 Managing the Carbon Footprint of Digital Systems

With the rapid development of artificial intelligence technology, the energy demand of smart computing infrastructure in cities has become increasingly significant, leading to a sharp increase in the power consumption of data centers. It is estimated that global greenhouse gas emissions from data centers account for approximately 2%, roughly equivalent to the entire aviation industry. During the pandemic, this figure even increased to 5-7% of the world's carbon emissions. Data from the China Academy of Information and Communications Technology also shows that in 2021, China's national data centers consumed a total of 216.6 billion kilowatt-hours of electricity, resulting in a carbon emissions volume of about 135 million tons, accounting for around 1.14% of the country's total carbon emissions, making it an important factor influencing the national "peak carbon" and "carbon neutrality" targets.

To enhance the carbon footprint of digital systems, efforts can be directed towards three main aspects: ***resource-efficient utilization, AI-enabled operational efficiency, and resource recycling***.

- **Resource-Efficient Utilization:** This involves utilizing cleaner energy sources for power supply, reducing the consumption of clean water resources, optimizing construction land use intensively, and maximizing the utilization of natural climate cooling sources.

- **AI-Enabled Operational Efficiency:** This includes intelligently optimizing data center cooling efficiency through AI technology, enhancing the operational efficiency of IT equipment, and flexibly and efficiently scheduling energy usage.

- **Resource Recycling:** On one hand, it involves the recovery and utilization of excess heat from data centers for heating within the data center itself, for supporting facilities in the vicinity, and for integration into the municipal heating network. On the other hand, it pertains to the recycling of data center equipment and facility materials.

Simultaneously, measures such as data compression, deduplication, and regular assessments of data centers can be implemented to reduce the carbon footprint of digital systems, decrease carbon emissions from digital infrastructure, contribute to environmental protection, and concurrently lower energy costs while improving system efficiency.

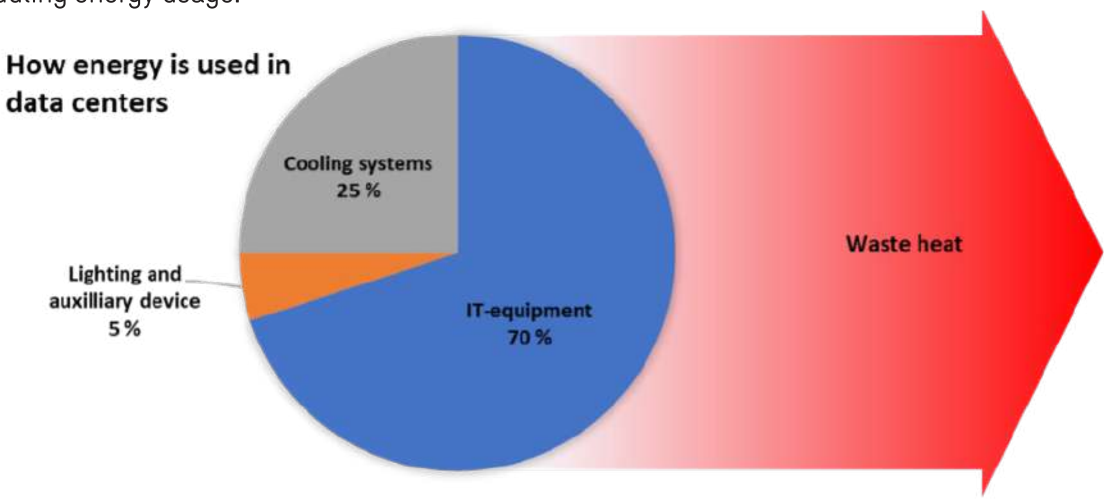


Figure 5-9: Composition of energy use in data centres Source:Hashnode.com

Figure 5-10: Google's green data centre in Europe Source: Sustainableitdecoded withgoogle.com

5.3 China's Urban Initiatives and Global Collaboration

As the world's largest developing country, China, while pursuing economic growth, has actively implemented a series of carbon reduction measures and formulated more specific and efficient implementation paths in various fields, including policy, finance, industry, and technology. Based on the "Dual Carbon" goals proposed in 2020, aiming to achieve the peak of carbon emissions by 2030 and carbon neutrality by 2060, Chinese cities have been deeply exploring multiple aspects to address the urgency of climate change and its global impact.

Against this backdrop, Chinese cities play a crucial role. China needs to actively share its carbon reduction practices, particularly in the pathways of digital technology and product development, digital urban planning, construction, and operational management. This is essential to address challenges and achieve emission reduction targets. These actions are not only a part of China's emission reduction efforts but also position the country as a key participant in global climate change mitigation. Through innovative sharing of urban planning experiences, deepening the application of digital technologies, and engaging in international cooperation, Chinese cities will play a pivotal role in advancing climate action and achieving emission reduction goals, contributing to the construction of a sustainable future.

5.3.1 China's Urban Practices in Net-Zero Carbon Transition

Proactively addressing climate change is an inherent requirement for China's sustainable development and a responsibility to contribute to the construction of a community with a shared future for humanity. In August 2023, during the main event of the National Ecological Day, the National Development and Reform Commission released significant achievements in China's commitment to carbon peaking and carbon neutrality, marking the third anniversary of this major declaration. These achievements span across eight key dimensions:

a. Governance System Enhancement: The central leadership of the Chinese Communist Party has incorporated carbon peak and carbon neutrality into comprehensive ecological civilization construction and socio-economic development plans. This commitment is clarified through policy documents and implementation plans to ensure the establishment and execution of a comprehensive policy system.

b. Facilitating Energy Transition: China is dedicated to reducing coal consumption, enhancing the efficiency of coal-fired power units, and accelerating the development of new and clean energy sources. This effort aims to diversify the energy supply and improve energy security.

c. Optimizing Industrial Structure: Through supply-side structural reforms, China is reducing crude steel production, fostering strategic emerging industries such as solar cells, lithium batteries, and electric vehicles. Simultaneously, there is a focus on guiding industrial upgrades and transitions, strengthening energy-saving, and carbon reduction measures.

d. Green Low-Carbon Development: Actively promoting green buildings, increasing the proportion of energy-efficient construction areas, improving transportation structures, boosting the production and sales of new energy vehicles, and advancing low-carbon transportation.

e. Enhancing Carbon Sink Capacity: Strengthening carbon sink capacity through ecosystem protection and restoration, national land greening actions, and increasing forest coverage.

f. Green Low-Carbon Policies: Implementing energy-saving policies, reinforcing dual control of energy consumption and carbon emissions, supporting green and low-carbon development through fiscal resource allocation and tax incentives, and introducing tools to support carbon reduction.

g. Dual Carbon Infrastructure: Establishing a unified carbon emission accounting system, reinforcing standardization, technological innovation, and pro-

Figure 5-11: The main event of the 2023 National Ecological Day Source: cpnn.com

fessional talent development to support the "Dual Carbon" goals.

h. Global Climate Governance: Actively participating in global climate governance, supporting international cooperation, promoting fair and rational global environmental governance, and simultaneously supporting the green and low-carbon development of developing countries to enhance their capacity to address climate change.

Simultaneously, China has undertaken extensive low-carbon pilot demonstration projects in the fields of energy, industry, construction, transportation, finance, and others. Encouraging cities to explore green and low-carbon development paths based on local conditions, China has implemented 81 low-carbon city pilot projects in three phases since 2010. These projects cover cities (districts, counties) with diverse regional characteristics, development levels, resource endowments, and working foundations. The pilot cities have solidly implemented their tasks, focusing on developing low-carbon development plans, formulating policies to promote the development of low-carbon industries, establishing greenhouse gas emission data statistics and management systems, implementing greenhouse gas emission control targets and responsibilities, and advocating green and low-carbon lifestyles and consumption patterns. These efforts have yielded positive results, accumulating valuable experience for local green and low-carbon development.

In summary, in the urban practices driving net-zero carbon transition, China actively mitigates climate change, adapts to climate change, perfects policy support, and actively participates in global governance to address climate change. Sharing China's experiences in addressing climate change and promoting net-zero carbon transition in cities and deepening global cooperation are crucial steps for China in the next phase.

5.3.2 Deepen International Exchanges and Cooperation

China attaches great importance to international cooperation in addressing climate change, firmly upholds multilateralism, and steadfastly supports the multilateral process of addressing climate change. It actively plays a constructive role in international climate change negotiations, engages in dialogue and pragmatic cooperation with various parties, actively promotes South-South cooperation on climate change, and supports the construction of a green "Belt and Road," contributing to the establishment of a fair, reasonable, cooperative, and win-win global climate governance system.

a. Deepening High-level Exchanges on Climate Change

- **Addressing Climate Change Has Become a Diplomatic Highlight for Leaders.** President Xi Jinping has delivered important speeches on numerous international occasions, proposing China's solutions for global climate governance and supporting significant progress in global climate governance. President Xi has also held multiple phone calls and video conferences with international leaders, including the UN Secretary-General, the U.S. President, and the UK Prime Minister, actively promoting international climate cooperation. Important consensus has been reached among China, France, and Germany on climate change and other issues.

- **Promoting High-level Dialogue and Exchanges to Consolidate Political Consensus.** In 2021, China and the U.S. climate envoys and negotiation teams engaged in more than 30 intensive consultations. In 2022, China continued to advance bilateral climate change dialogues such as the "China-EU Carbon Emission Trading Policy Dialogue," continuously strengthening China-EU cooperation in carbon markets, low-carbon cities, and other areas. China hosted the first high-level meeting on climate change for BRICS countries, participated in the G20 climate

Figure 5-12: Opening of the 15th meeting of the Conference of the Parties to the Convention on Biological Diversity in Kunming, Yunnan Province
Source: Chinadaily.com

and energy joint ministerial meeting, and advocated the establishment of a sustainable finance research group.

b. Driving Multilateral and Bilateral Climate Change Negotiations

- **China Fully and Actively Participates in the Main Channels of International Negotiations, Including the Convention and its Paris Agreement.** Adhering to the concept of a community with a shared future for humanity, China coordinates external cooperation and struggles, pushing for the adoption of the Shamshayek Implementation Plan at the COP meetings and striving to build a fair, reasonable, cooperative, and win-win global environmental governance system. The Chinese delegation attended COP26 and COP27, participating comprehensively in negotiations on various agenda items, actively engaging in dialogues and coordination with all parties, playing a positive and constructive role.

- **Actively Engaging in Negotiations Outside the Convention, China Collaborates to Advance the Climate Multilateral Process.** Upholding the principles of fairness, common but differentiated responsibilities, and respective capabilities, China insists on the "bottom-up" nationally determined contributions mechanism and firmly maintains the central position of the Convention. Actively participating in dialogues and consultations on climate change in various channels such as the International Maritime Organization (IMO), the Asia-Pacific Economic Cooperation (APEC), the World Trade Organization (WTO), and the International Civil Aviation Organization, China introduces its positions on key issues in international climate negotiations, guiding parties to bridge differences and move towards common goals.

c. Strengthening Pragmatic Cooperation on Climate Change

- **Deepening Bilateral and Multilateral Cooperation Mechanisms in the Climate Field.** China promotes the construction of the Asia Center for Solu-

Figure 5-13: 27th United Nations Climate Change Conference

Source: News.yale.edu

tions Based on Nature and advances exchanges and cooperation with the EU, Germany, ASEAN, the UK, Finland, Denmark, Japan, South Korea, New Zealand, Singapore, South Africa, Uruguay, and other countries and organizations. China encourages international financial institutions such as the World Bank, the Asian Development Bank, the Asian Infrastructure Investment Bank, and the New Development Bank of BRICS to increase efforts in mobilizing funds to balance support for climate projects in developing countries. At the same time, China actively sends talent to international organizations, strengthening the internationalization of talent training.

- **South-South Cooperation Achieves New Progress.** China provides climate funding support to developing countries and conducts training activities. As of July 2022, China has allocated over 1.2 billion RMB for South-South cooperation on climate change, signing 43 cooperation documents with 38 developing countries. Collaborating with Laos, Cambodia, Seychelles, and others to build low-carbon demonstration zones, China has implemented 40 projects for climate change mitigation and adaptation in more than thirty developing countries, including Ethiopia, Pakistan, Samoa, Chile, Cuba, and Egypt.

- **Collaborating to Build the "Green Silk Road."** In 2021, China jointly launched the "Belt and Road" Green Development Partnership Initiative with 28 countries and continuously improved the construction of the International Alliance for Green Development of the "Belt and Road" (the Alliance). Leveraging the "Belt and Road" Ecological and Environmental Big Data Service Platform, China has developed tools for assessing environmental risks in overseas investments and compiled the "Belt and Road" Ecological and Environmental Big Data Report. This guides enterprises in implementing green development concepts, conducting green investment cooperation, and promoting the construction of a green "Belt and Road."

In the process of promoting the net-zero carbon transition of cities, China has strengthened international exchanges and cooperation through various means across different dimensions. Actively engaging in global governance efforts to address climate change, China aims to collectively tackle climate change and promote global sustainable development. Building upon existing initiatives, China will continue to enhance international exchanges and cooperation. Looking ahead, global cities need to reach consensus on key issues related to net-zero carbon transition. This will be crucial for cities worldwide to collaboratively address the global climate crisis and achieve a sustainable future.

Figure 5-14: Schematic diagram of South-South cooperation Source: Idea.org

5.4 Global Urban Digital Net-Zero Carbon Action Initiatives

As climate change intensifies globally, nations must take immediate action to stabilize Earth's temperature and mitigate the impacts of climate change. Achieving net-zero emissions is a key goal, and digital innovation is an effective pathway to attaining this objective. Therefore, to actively guide digital technology towards sustainable urban development, fostering the integration of technology with human values, and promoting the harmonious coexistence of cities and nature, this report proposes the following five major initiatives:

1 Elevate Urban Management with Digital Concepts, Implement Comprehensive Carbon Reduction Actions

- **Digital Empowerment of Carbon Strategies:** Leaders, policymakers, and the public need to recognize the inseparable connection between digitization and net-zero carbon. Utilizing digital technology, establish a feedback mechanism for effective communication between grassroots and upper-level entities. This ensures a dynamic balance for carbon neutrality, creating a positive feedback loop of "planning-implementation-accounting-analysis" for carbon management.

- **Enhance Digital Education Dissemination:** Establish a widespread awareness mechanism to communicate the benefits of digital net-zero carbon to citizens. This includes explaining how digital technology can reduce energy waste, lower carbon emissions, improve air quality, and enhance the quality of life for urban residents. Schools, communities, and media play crucial roles in promoting the benefits of sustainable cities.

- **Digital Full-Process Monitoring and Feedback:** Create regular carbon emission reports using digital tools to convey the outcomes and efforts of carbon reduction actions to internal and external stakeholders. Ensure transparency and compliance by tracking key performance indicators to guarantee the successful implementation of carbon reduction plans.

2 Utilize Digital Technology to Facilitate Energy Transition, Effectively Reduce Greenhouse Gas Emissions

- **Smart Energy Management Systems:** Develop intelligent power grid systems that utilize technologies such as the Internet of Things (IoT), big data, blockchain, and cloud computing to monitor, analyze, and manage urban energy usage in real-time. This aims to minimize waste and enhance efficiency.

- **Integration of Renewable Energy Networks:** Coordinate the production and distribution of renewable energy sources like solar, wind, and bioenergy using digital technology. Establish an energy internet to optimize the energy structure further, ensuring cities maximize the use of clean energy and reduce dependence on fossil fuels. Governments can incentivize residents and businesses to invest in renewable energy.

- **Smart City Planning for Zero-Carbon Systems:** Introduce technologies like the Internet of Things, big data, artificial intelligence, and cloud computing into urban planning digital tools. Apply these tools to areas such as urban construction and housing, water usage, traffic management, and recycling, optimizing carbon emissions and energy efficiency at each stage. Establish a carbon digital base and a "double carbon" brain to assist in more precise energy supply and demand data for urban planning decisions.

3 Strengthen International Cooperation Through Digital Platforms, Jointly Address Global Climate Change

- **Digital Platforms and Data Sharing:** Establish digital platforms to facilitate a mechanism for sharing carbon emission data across cities and borders, promoting collaborative emission reduction policies globally.

- **Open Data Standards and Protocols:** Develop global standards to enable interoperability of carbon emission data between different cities while encouraging transparency and traceability.

- **Support City Partnership Initiatives:** Promote the development of transnational digital net-zero carbon city partnerships or alliances, such as C40 CITEIS, to unite against the climate crisis. Additionally, establish international cooperation funds for digitized solutions, supporting the development and implementation of digital initiatives between cities to foster broader collaboration.

4 Drive Public Engagement Through Digital Culture, Nurturing the Development of Green Human Values

- **Personal Carbon Footprint and Carbon Accounts:** Develop digital carbon footprint applications, enabling individuals to track carbon emissions from their clothing, food, housing, and transportation activities. Quantify and link personal carbon emission account levels to various life scenarios, offering suggestions to reduce emissions.

- **Data Visualization and Online Communities:** Establish online communities using data visualization technology to display urban carbon emissions, energy usage, and environmental conditions. Develop online platforms to actively engage the public in the planning and decision-making processes of carbon-neutral cities. Create climate change discussion communities to promote public participation, information sharing, and mutual assistance.

- **Green Digital Culture Public Events:** Organize public events such as exhibitions, lectures, and creative competitions centered around green digital culture themes. Utilize technologies like virtual and augmented reality to encourage artists, producers, and creators to express information about climate change and sustainable development in digital forms.

5 Drive Green Consumption Through Digital Finance, Stimulating Innovative Low-Carbon Economic Development

- **Establish Inclusive Carbon Markets:** Develop various forms of digital carbon markets to facilitate carbon emission trading, encouraging enterprises, communities, and individuals to adopt emission reduction measures and invest in carbon-neutral initiatives.

- **Innovate Green Consumption Business Models:** Foster digitally-driven innovative business models, such as the sharing economy, electric transportation, and smart city solutions. These industries provide new low-carbon alternatives for urban areas. Digital technology can also assist in tracking and verifying the environmental performance of green products, encouraging consumers to purchase more eco-friendly goods and services.

- **Invest in Innovation and Employment Opportunities:** Governments and businesses should increase research and investment in digital and green technology. This will promote new economic growth while creating job opportunities, including the installation and maintenance of renewable energy, the development and maintenance of smart city technologies, and the growth of the green building industry. Governments and businesses should actively train and absorb the workforce to meet the demands of these emerging fields.

Figure: Wind Energy. Source: Pexel.com

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Digital Innovations Empower Urban Net-Zero Carbon Transition

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