Big Earth Data in Support of the Sustainable Development Goals

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Chinese Academy of Sciences

International Research Center of Big Data for Sustainable Development Goals

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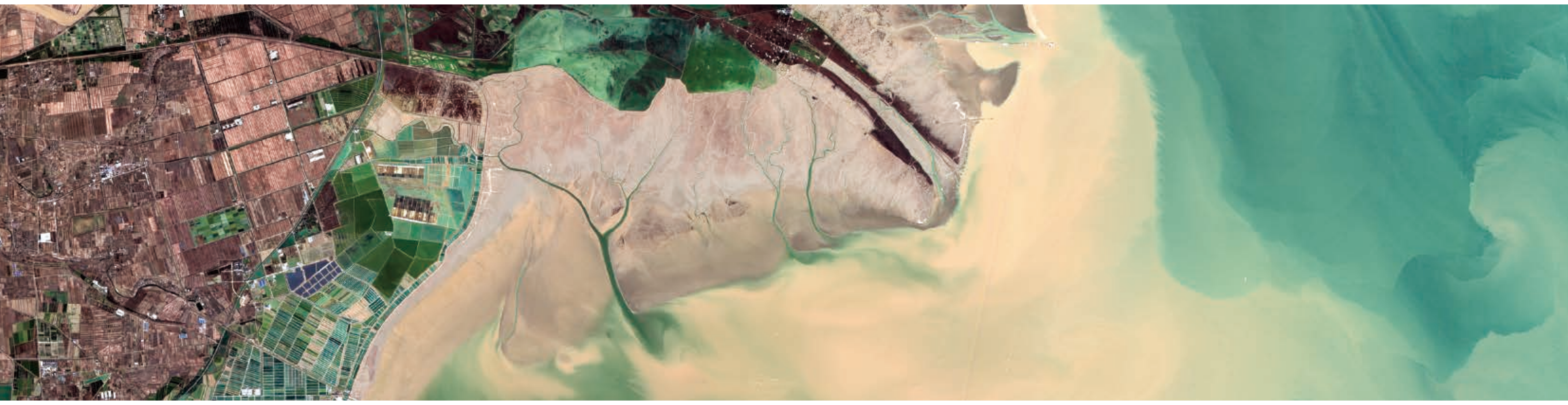


Preface

From 2015 to the present, the implementation of the United Nations' *Transforming our world: the 2030 Agenda for Sustainable Development* (referred to as the 2030 Agenda) has reached its halfway point. During this period, progress on the Sustainable Development Goals (SDGs) has encountered serious challenges and difficulties despite the overall advancements. The international community has gained deeper insights into long-term issues such as climate change and biodiversity loss, but further efforts are needed to enhance implementation. Unexpected events like the COVID-19 pandemic and regional conflicts have had significant and far-reaching impacts on society, the economy, and the environment.

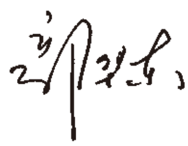
It is important for the international community to learn both experience and lessons of the first half of the 2030 Agenda, so that we can enhance the implementation of the SDGs in the second half and explore directions for future sustainable development. The slow progress during the initial phase underscores the global inadequacy in addressing long-term risks as well as short-term crises in the process of promoting sustainable development. The lack of timely and accurate data remains a weakness in our response to both long-term and short-term issues and is a bottleneck hindering the implementation and monitoring of the SDGs and the formulation of science-based decisions.

In September 2021, Chinese President Xi Jinping proposed the Global Development Initiative (GDI) during the 76th United nations General Assembly. The GDI aims to deepen international cooperation, accelerate the implementation of the 2030 Agenda and promote stronger, greener, and healthier development. It places a special emphasis on advancing collaboration in areas such as digital connectivity in the digital age to expedite the realization of the 2030 Agenda. The GDI is committed to building a global community of development and a crucial foundation in this endeavor is the promotion of digital technology. Big Earth Data, as a representative form of such technology, can play a vital role in filling the gaps in current SDG statistical data and spatial-temporal information.

2023 marks the third anniversary of President Xi Jinping's announcement of the establishment of the International Research Center of Big Data for Sustainable Development Goals (CBAS) in China, and also the fifth consecutive year of publishing the report *Big Earth Data in Support of the Sustainable Development Goals* (referred to as the report). Over the past few years, the research team has made use of the increasingly refined Big Earth Data platform and leveraged the advantages of objective scientific data and rich spatial-temporal information to assess the midterm progress on sustainable development in China and globally. The team's focus has been on exploring the bottlenecks hindering sustainable development and identifying future development directions.

This year's report focuses on the midterm evaluation of sustainable development in China and globally through Big Earth Data. It aims to further expand data products for SDG indicators, broaden the depth of indicator contents, complete progress evaluations of all environment-related SDG indicators in China, and actively provide public data products to serve all the countries, particularly developing countries in terms of evaluating the implementation of the 2030 Agenda. It also provides recommendations on future science-based decision-making, accelerating sustainable development processes, building big data acquisition capabilities, and adjusting and optimizing indicators. The report stands as a scientific support for the implementation of the 2030 Agenda.

The report is a collaborative effort, written by over 160 researchers from more than 50 organizations, including research institutes and universities in the field of sustainable development and big data. The project has received strong support from the Chinese Academy of Sciences and various government departments, and the team members have dedicated significant efforts to this endeavor. We express our heartfelt gratitude to all those involved in making this report a reality.



Guo Huadong
Director of the International Research Center of Big Data for Sustainable Development Goals
Member of the UN 10-Member Group to support the TFM for SDGs (2018–2021)

Executive Summary

This report gives full play to the advantages and characteristics of Big Earth Data. It focuses on 25 targets related to seven Sustainable Development Goals (SDGs), including SDG 2 (Zero Hunger), SDG 6 (Clean Water and Sanitation), SDG 7 (Affordable and Clean Energy), SDG 11 (Sustainable Cities and Communities), SDG 13 (Climate Action), SDG 14 (Life Below Water), SDG 15 (Life on Land), as well as the interactions among SDG indicators, resulting in 41 research cases. From three aspects: data products, methods and decision-making, this report shows the results of monitoring and midterm evaluation of relevant SDG indicators at four scales: global, regional, national, and typical areas. The report represents an innovative practice of big data in support of SDG implementation and can provide scientific reference for decision-makers.

Regarding SDG 2 (Zero Hunger), the report focuses on four indicators of two targets and conducts global/China midterm progress evaluations. The research findings indicate that China is moving towards sustainable food production, on the basis of progress towards meeting nurtitional needs. The stunting rate of children under six (SDG 2.2.1) in China decreased from 8.1% in 2013 to 4.8% in 2017. The overweight rate of children under six (SDG 2.2.2) decreased from 8.4% in 2013 to 6.8% in 2017. The anemia prevalence among women of reproductive age (SDG 2.2.3) decreased from 15.0% in 2012 to 14.5% in 2018. Regarding the proportion of the area under productive and sustainable agriculture (SDG 2.4.1), the global total cropland area has shown a steady growth trend, with an increase rate of 30,500 km^2 per year from 2015 to 2022. The area of China's well-facilitated farmland increased from about 20% of the total cropland area in 2015 to over 50% in 2022. The efficiency of resource utilization, including fertilizers, pesticides, irrigation water, and land, improved by 8.8% to 25.3%. The income of practitioners increased on average by 56.4%. China's terraced land area slightly increased. The existing terraced fields reduce the soil water erosion of cropland in China by about 50%. Notably, the organic carbon content in China's cropland topsoil increased by 3.4% from 2015 to 2020.

Regarding SDG 6 (Clean Water and Sanitation), the report focuses on eight indicators of six targets and conducts global/China midterm progress evaluations. The research findings reveal that since 2001, the transparency of 41.4% of large lakes and reservoirs worldwide (SDG 6.3.2) has shown a significant upward trend; the overall improvement rate in cropland water-use efficiency in agricultural areas worldwide has been 3.5%; the distribution area of lakes and reservoirs has grown by 719.1 km^2 per year globally. In China, significant progress has been made in achieving SDG 6. Since 2015, the surface water sources meeting the water quality safety standards increased by 3.5 percentage points. The ratio of public toilets per 10,000 urban residents (SDG 6.2.1a) increased by 11.2%. The number and capacity of wastewater treatment plants (SDG 6.3.1) increased by 111.6% and 56.1%, respectively. 26 provinces in China saw increases in the proportion of surface water bodies with good water quality (SDG 6.3.2). China's overall water stress level (SDG 6.4.2) decreased from 66% to 58%. The area of natural and artificial water bodies (SDG 6.6.1) has been increasing, with reservoir water surface area growing by approximately 7%. From 2001 to 2019, water use efficiency of wheat, corn, and rice cultivation in China increased by 33.4%, 20.0%, and 14.1%, respectively. China's evaluation score of integrated water resource management implementation (SDG 6.5.1) increased from 75 in 2017 to 79 in 2020.

Regarding SDG 7 (Affordable and Clean Energy), the report focuses on six indicators of five targets and conducts global/China midterm progress evaluations. The research findings indicate that China has achieved significant progress in all SDG 7 indicators. By 2020, the global electrified built-up areas (SDG 7.1.1) improved significantly compared to 2014, and China achieved complete access to electricity in 2015. China's population relying on clean cooking energy and technology (SDG 7.1.2) reached 83.55% in 2022. China's clean energy transition has made significant progress. By 2022, China's wind power and photovoltaic installed capacity increased by 2.8 and 9.2 times, respectively, compared to 2015. China's renewable energy electricity transmitted via ultra-high voltage increased by 1.69 times from 2016 to 2021. The energy consumption per unit of Gross Domestic Product in China (SDG 7.3.1) decreased by one-fifth from 2014 to 2021. China has established a systematic framework for international cooperation in energy, in terms of energy policies, energy project, green energy utilization, and energy technology cooperation (SDG 7.a.1/SDG 7.b.1), contributing to global energy transition.

Regarding SDG 11 (Sustainable Cities and Communities), the report examines progress towards nine indicators under eight targets at the global and Chinese scales. From 2015 to 2020, the proportion of the urban population with convenient access to public transport (SDG 11.2.1) increased by 3.4% globally. Urban land-use efficiency (SDG 11.3.1) increased worldwide. Heritage conservation (SDG 11.4.1) improved globally, and the number of affected people due to disasters (SDG 11.5.1) significantly decreased. Between 2015 and 2022, Particulate Matter 2.5 ($PM_{2.5}$) concentration (SDG 11.6.2) dropped from 21.6 μg/m^3 to 19.4 μg/m^3 globally. For China, considerable progress has been achieved in multiple SDG 11 indicators. The urban population in slum areas (SDG 11.1.1) decreased by 30.8%; the proportion of the population with convenient access to public transport significantly increased; disaster-affected people and deaths (SDG 11.5.1) and direct economic losses (SDG 11.5.2) exhibited a clear downward trend; the exposure risk to $PM_{2.5}$ (SDG 11.6.2) decreased to 44.2% for Chinese residents. Additionally, ecological greening efforts for urban construction land (SDG 11.7.1) have proved effective, and the central and eastern regions of China have outperformed the western and northeastern regions in terms of urban and rural regional development (SDG 11.a).

Regarding SDG 13 (Climate Action), the report examines midterm progress towards four targets through seven indicators globally and in China. The research finds that progress has been made in disaster prevention and reduction both in China and the world, but significant challenges remain in reducing greenhouse gas emissions. From 2016 to 2021, the global annual number of disaster-affected people and deaths (SDG 13.1.1) decreased by 42.2% and 78.0%, respectively, compared to the period from 2000 to 2015. China also witnessed a significant reduction from 2016 to 2021 in the number of disaster-affected and deceased/missing people per 100,000 population by 57.7% and 64.8%, respectively, compared to the period from 2010 to 2015. China has developed comprehensive national disaster risk reduction policies (SDG 13.1.2) based on the Sendai Framework for Disaster Risk Reduction, and the proportion of local governments with disaster risk reduction strategies (SDG 13.1.3) has reached 100%. Moreover, after 2020 China set targets for carbon emissions peak and carbon neutrality, forming a strategic framework to address climate change (SDG 13.2.1/13.b.1). However, global greenhouse gas emissions (SDG 13.2.2) has resumed an upward trend since 2021 after a temporary decrease in 2020, and similarly China faces considerable pressure on emissions control. Climate change education (SDG 13.3.1) in China is still at its early stages, although the introduction of the "dual carbon" goals has led to increased public awareness of climate change issues.

Regarding SDG 14 (Life Below Water), the report assesses China's midterm progress in four targets. Notable progress was observed in all indicators. For instance, marine pollution reduction efforts (SDG 14.1) led to significant decreases in the concentrations of dissolved inorganic nitrogen, dissolved inorganic phosphorus, and reactive silicate in the coastal waters of Eastern China from 2009 to 2019. In 2018, the abundance of floating debris in China's coastal waters decreased by approximately 25% compared to the average value from 2010 to 2014. From 2018 to 2021, the average abundance of microplastics in China's coastal waters was at a low-to-medium level. Moreover, efforts to protect marine ecosystems (SDG 14.2) resulted in a net increase of 16% in China's mangrove area from 2015 to 2020, an increase in the value of coastal wetlands in typhoon preparedness, and improved ecological health in typical coastal bays. In terms of protecting coastal and marine areas (SDG 14.5), the pace of returning enclosure to the sea and wetlands in coastal China continued to increase, with significant growth observed from 2018 to 2020. Sustainable management of aquaculture (SDG 14.7) in China was evident, showing a decreasing trend in the area of coastal aquaculture ponds from 2015 to 2020 and a shift towards raft aquaculture, which grew orderly in area from 2015 to 2021 with a trend of its distribution moving farther away from the coastline.

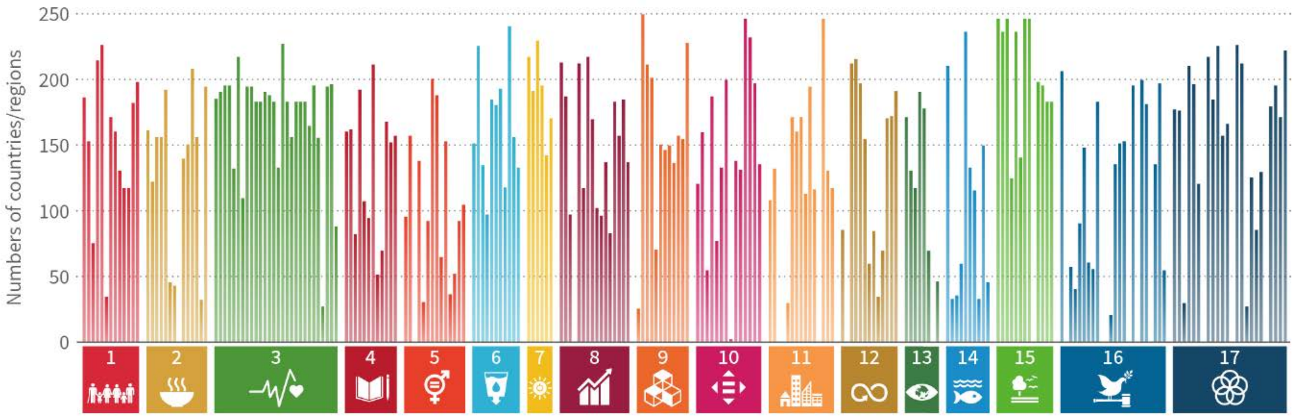
Regarding SDG 15 (Life on Land), the report examines midterm progress towards five targets through six indicators globally and in China. China made significant advancements in all SDG 15 indicators. Notably, China's forest cover (SDG 15.1.1) showed a clear increasing trend, with significant success in afforestation efforts. Since 2015, global land degradation (SDG 15.3.1) showed signs of improvement, and China achieved land degradation neutrality ahead of schedule. During the monitoring period (2015–2020), the average annual net restoration rate of land increased by nearly 5% compared to the baseline period (2000–2015). Regarding the protection of mountain ecosystems, by 2020, two-thirds of China's key protected wild species and 86.9% of priority-protected natural ecosystems in mountain areas were covered by natural protected areas, providing significant safeguards for mountain biodiversity conservation (SDG 15.4.1). The Mountain Green Cover Index (SDG 15.4.2) was stable globally and in China between 2015 and 2020, and China has also achieved this indicator. Furthermore, efforts to protect threatened species, as indicated by the Red List Index for higher plants in China (SDG 15.5.1), showed a slight increase from 2013 to 2020, indicating stability and improvement in conservation efforts. Additionally, efforts to prevent and control invasive alien species (SDG 15.8.1), such as potato beetle among six typical pests, exhibited positive results from 2012 to 2020.

Finally, the report also discusses SDGs' integrated assessment and interactions, examining four themes: integrated evaluation of SDGs in 285 cities at or above the prefecture level of China, SDGs' synergies and trade-offs, spatial spillover effects, and future scenario simulations. The report finds significant spatial differences in the comprehensive scores and balance scores of SDGs across China's cities at or above the prefecture level, with urban clusters outperforming non-cluster areas in SDGs development. The analysis also reveals that there are more synergies than trade-offs between SDGs among cities, with more intensive interactions observed in urban clusters such as the Yangtze River Delta, Chengdu-Chongqing, and the Pearl River Delta. The report points out the importance of urban cluster strategies in driving sustainable urban development, with a focus on key goals like SDG 4 (Quality Education), SDG 11 (Sustainable Cities and Communities), SDG 12 (Responsible Consumption and Production) and SDG 15 (Life on Land) to promote the overall achievement of the SDGs.

Introduction

As we reach the midpoint in the implementation of the *Transforming our world: the 2030 Agenda for Sustainable Development* (referred to as the 2030 Agenda) in 2023, we need to assess, at this moment of reflection, the current progress on the SDGs with more accurate data. This work can help us to have a big-picture view of the issues facing us all globally as well as individual nations, and to find science-based solutions that will see us through the second half of the implementation process.

According to the *Sustainable Development Goals Report* issued by the United Nations that monitored progress on the 17 goals (UN, 2022; UN, 2023a) and our own assessment of more than 230 indicators (Figure 1-1), about half the countries of the world are severely lacking in progress data with respect to the indicators, timely updates and geospatial information. This lack of data severely hinders the ability of nations to monitor progress and to make informed decisions. The midterm review represents an opportunity to examine the progress and weaknesses in our implementation worldwide and also to enhance data acquisition. As of now, out of the 230 plus indicators, 35% exhibit a lack of data at Tier II (having methods but no data). Even for indicators where data is available, data distribution is extremely uneven across countries and sectors. Developing and underdeveloped nations, in particular, are hampered by the lack of large-scale data computing capacity and adequate resources and are badly in need of reliable global data products.



↑ Figure 1-1 Numbers of countries/regions having data on indicators

Big Earth Data in Support of the SDG Midterm Evaluation

The United Nations Secretary-General's Roadmap for Digital Cooperation aims to promote digital technology in accelerating the process of sustainable development (UN, 2020a). Big data is an important method and output of digital technology. We have been using Big Earth Data, encompassing multi-source data such as satellite observations, station records, survey statistics, internet media, and basic geographic data, to make up for the lack of statistical data and at the same time to provide rich spatial-temporal information to show the spatial differences and progress in the indicators. The Sustainable Development Science Satellite 1 (SDGSAT-1) launched in November 2021 is a scientific satellite dedicated to serving the 2030 Agenda. Currently, the satellite data have been shared globally to further enhance SDG data acquisition capability.

From 2019 to 2022, we released four reports on Big Earth Data in Support of the Sustainable Development Goals (SDG Reports, http://www.cbas.ac.cn/en/publications/reports/) to promote the achievement of these goals in China and the rest of the world. The 2023 Report continues to monitor progress on indicators at the Chinese and global scales from the perspectives of method, data and decision support. The focus of this year's Report is on midterm progress assessment of indicators in China and globally. More than one third of the over 230 SDG indicators are environment-related (UNEP, 2021a), where the temporal and spatial advantages of Big Earth Data are most evident. As research on Big Earth Data deepens, the data that can be used to calculate indicator implementation is also increasing and routinely being updated.

Over the past five years we have mainly provided public data products at the global scale on multiple SDG indicators, such as on cropland (SDG 2), natural and artificial water bodies quality (SDG 6), electrification (SDG 7), urban impervious surface and urban public space (SDG 11), greenhouse gas emissions and natural disaster impact (SDG 13), aquaculture and mangrove distribution (SDG 14), forest cover and land degradation (SDG 15), and data products from SDGSAT-1. These products are world-leading in resolution, timeliness, and accuracy and can be directly applied to the assessment of SDG implementation worldwide. At the same time, we have built the Big Earth Data sharing service platform and the online display platform for the sharing, display and online calculation of indicators.

At the Chinese scale, based on the data sets from the 2019–2023 reports and national and United Nations (UN) statistics as well, analysis was done on the progress on 98 mainly environmental indicators in China from 2010 to 2022 (Figure 1-2). Some quantitative findings on the progress are exploratory results of applying critical Big Earth Data processing, analytics and other innovative methods. The results show consistent and steady improvement on the indicators assessed during the period 2010–2022. Between 2010 and 2015, 76.5% of those indicators improved continuously while 14.7% deteriorated. Between 2015 and 2022, the improvement trend was further strengthened, with 81% continuing to improve and none deteriorating. In 2015, only 13 out of the 98 indicators were achieved, but by 2022, more than half (51 indicators accounting for 52%) were achieved, meeting the 2030 Agenda ahead of schedule. The data show that China has made great progress on environmental indicators since its implementation of the SDGs in 2015. Among the assessed indicators, more than 60% under the three Goals—SDG 2 Zero Hunger, SDG 13 Climate Action and SDG 15 Life on Land— have already been achieved.

Discussion on SDG Indicators

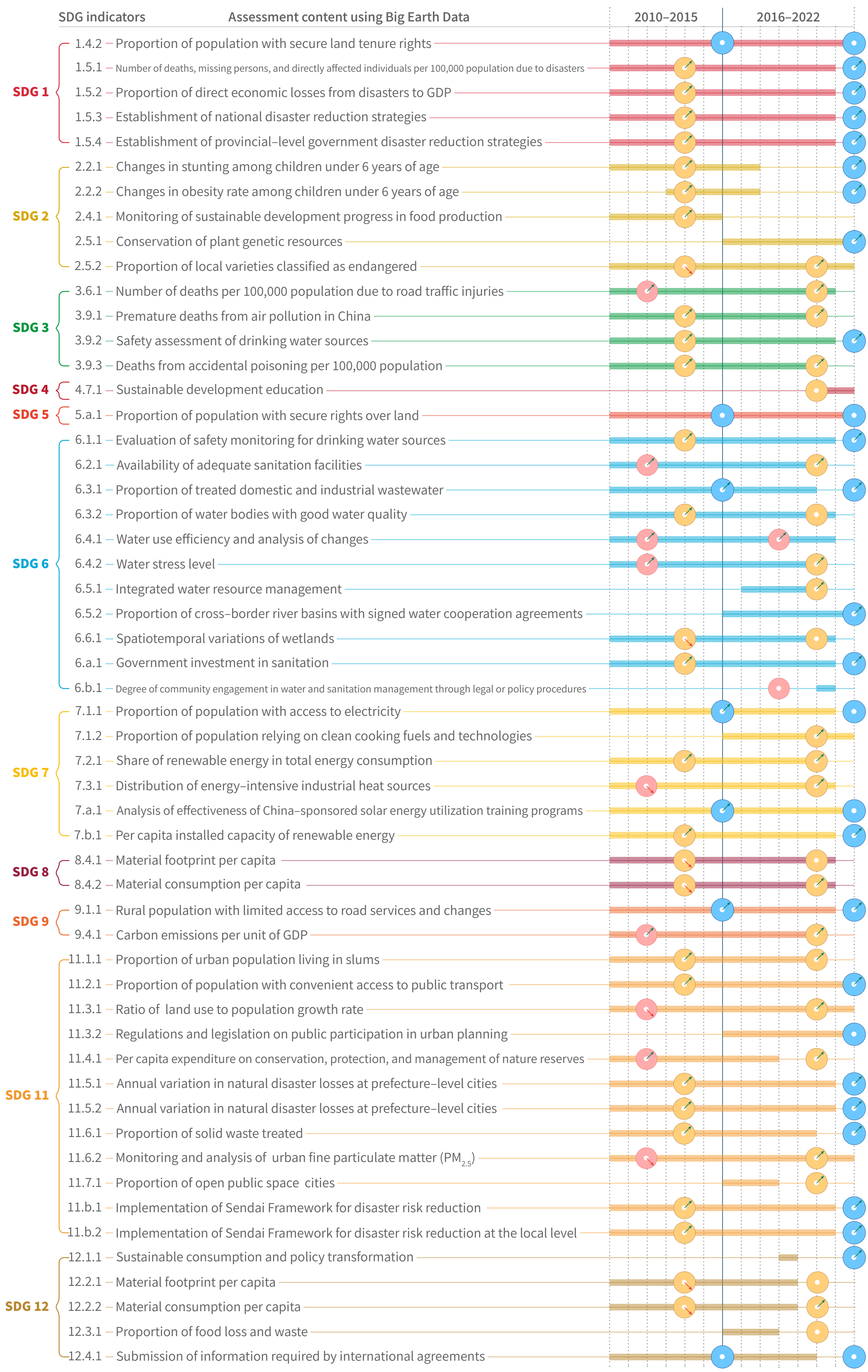
Given its advantage of quick update, repeatability and broad coverage, big data can play an important role in closing the gap in national data and computing indicator-related data with global consistency (Guo, 2019; 2020; 2021). However, based on our long-term indicator research and tracking, from the perspective of big data analysis and computing, we propose three improvements to the definition and evaluation criteria of some indicators:

(1) The data comparability standards for some indicators are not high. The data obtained according to some indicators' definitions fail to reflect differences in population, level of development and geography between countries. For example, under SDG 13.2.2 annual total greenhouse gas emissions, the differences in the size of population and economy between countries are not considered.

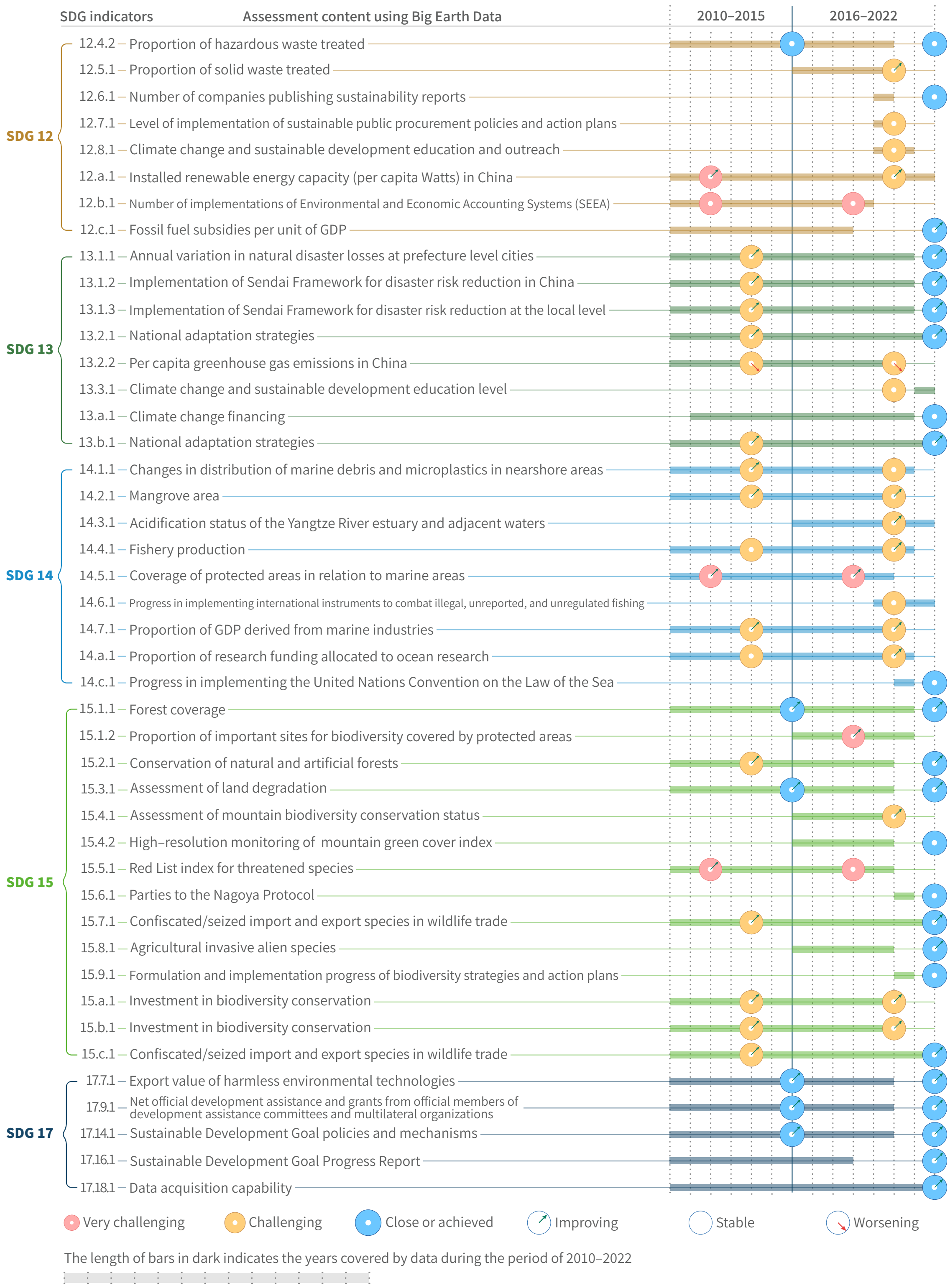
(2) The evaluation of environmental indicators requires more quantitative standards. Some criteria cannot be quantified, making it difficult to measure progress or achievement. For example, SDG 14.a.1, which is the proportion of total research budget allocated to research in the field of marine technology. It is hard to quantify the proportion at which the indicator is achieved and an increase in the proportion of marine research could lead to a decrease in the proportion of other research activities, such as in agriculture and climate change.

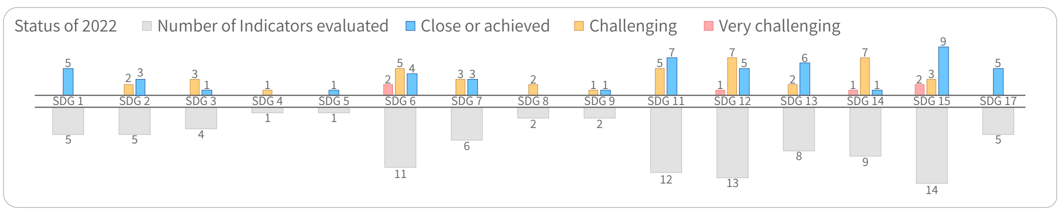
(3) The spatial data of some indicators are difficult to obtain. Some indicators are defined in a way that distinguishes between men and women and persons with disabilities, such as SDG 11.2.1, which is the proportion of population that has convenient access to public transport and SDG 11.7.1, which is the average share of the built-up area of cities that is open space for public use for all. They may intend to emphasize the protection of vulnerable groups, but the population grids with disaggregated data of men and women and persons with disabilities in cities are difficult to obtain on a broad basis, and statistical data alone cannot reflect spatial differences in the calculation of indicators.

In view of the current worldwide differences in countries' data acquisition capacity and issues concerning the setting of indicators, we recommend the following: (1) nations should strengthen support in the continued enhancement of their ability of using big data in indicator calculation. (2) the UN may improve the clarity of definitions and criteria of some of the indicators based on data availability considerations. The enhanced clarity could allow globally consistent big data to play a more significant role and move us towards greater data equity and availability.



↑ Figure 1-2 Chinese midterm progress evaluation on 98 SDG indicators based on Big Earth Data


SDG indicators
Assessment content using Big Earth Data
2010–2015
2016–2022
SDG 12
12.4.2 – Proportion of hazardous waste treated
12.5.1 – Proportion of solid waste treated
12.6.1 – Number of companies publishing sustainability reports
12.7.1 – Level of implementation of sustainable public procurement policies and action plans
12.8.1 – Climate change and sustainable development education and outreach
12.a.1 – Installed renewable energy capacity (per capita Watts) in China
12.b.1 – Number of implementations of Environmental and Economic Accounting Systems (SEEA)
12.c.1 – Fossil fuel subsidies per unit of GDP
SDG 13
13.1.1 – Annual variation in natural disaster losses at prefecture level cities
13.1.2 – Implementation of Sendai Framework for disaster risk reduction in China
13.1.3 – Implementation of Sendai Framework for disaster risk reduction at the local level
13.2.1 – National adaptation strategies
13.2.2 – Per capita greenhouse gas emissions in China
13.3.1 – Climate change and sustainable development education level
13.a.1 – Climate change financing
13.b.1 – National adaptation strategies
SDG 14
14.1.1 – Changes in distribution of marine debris and microplastics in nearshore areas
14.2.1 – Mangrove area
14.3.1 – Acidification status of the Yangtze River estuary and adjacent waters
14.4.1 – Fishery production
14.5.1 – Coverage of protected areas in relation to marine areas
14.6.1 – Progress in implementing international instruments to combat illegal, unreported, and unregulated fishing
14.7.1 – Proportion of GDP derived from marine industries
14.a.1 – Proportion of research funding allocated to ocean research
14.c.1 – Progress in implementing the United Nations Convention on the Law of the Sea
SDG 15
15.1.1 – Forest coverage
15.1.2 – Proportion of important sites for biodiversity covered by protected areas
15.2.1 – Conservation of natural and artificial forests
15.3.1 – Assessment of land degradation
15.4.1 – Assessment of mountain biodiversity conservation status
15.4.2 – High-resolution monitoring of mountain green cover index
15.5.1 – Red List index for threatened species
15.6.1 – Parties to the Nagoya Protocol
15.7.1 – Confiscated/seized import and export species in wildlife trade
15.8.1 – Agricultural invasive alien species
15.9.1 – Formulation and implementation progress of biodiversity strategies and action plans
15.a.1 – Investment in biodiversity conservation
15.b.1 – Investment in biodiversity conservation
15.c.1 – Confiscated/seized import and export species in wildlife trade
SDG 17
17.7.1 – Export value of harmless environmental technologies
17.9.1 – Net official development assistance and grants from official members of development assistance committees and multilateral organizations
17.14.1 – Sustainable Development Goal policies and mechanisms
17.16.1 – Sustainable Development Goal Progress Report
17.18.1 – Data acquisition capability
Very challenging
Challenging
Close or achieved
Improving
Stable
Worsening
The length of bars in dark indicates the years covered by data during the period of 2010–2022


Status of 2022
Number of Indicators evaluated
Close or achieved
Challenging
Very challenging
SDG 1
SDG 2
SDG 3
SDG 4
SDG 5
SDG 6
SDG 7
SDG 8
SDG 9
SDG 11
SDG 12
SDG 13
SDG 14
SDG 15
SDG 17

SDG 2
Zero Hunger

Background

As we approach the midpoint of the 2030 Agenda, the world is facing challenges such as climate change, extreme weather events, political conflicts, economic shocks, and growing inequality, which have diverted us from the track of achieving SDG 2 Zero Hunger (UN, 2022). Furthermore, projections indicate that by 2030, there will still be around 600 million people worldwide facing hunger, a level similar to that in 2015 when the 2030 Agenda was launched (FAO *et al*., 2023). Achieving the Zero Hunger goal requires a 28% increase in global average agricultural productivity over the next decade, which is more than three times the growth rate of the past decade (OECD and FAO, 2022).

Sustainable land, soil, and water resource management form the foundation for ensuring nutrition, diversified diets, and resource-efficient value chains in the transition to sustainable consumption. About 90% of the calories and 80% of the protein consumed by humanity come from cropland (Kastner *et al*., 2012). However, due to population growth, per capita cropland area decreased by about 18% from 2000 to 2020 (FAO, 2022). Additionally, evidence suggests that the growth rate of agricultural productivity is slowing down, and high pollution and emissions have pushed production capacity to its limits, leading to land and environmental degradation (FAO, 2021).

The Food and Agriculture Organization of the United Nations (FAO), being the custodian agency for nine of the 14 indicators under SDG 2 and the contributing agency for another indicator, has developed a comprehensive system for statistical survey data collection and sharing. This system provides valuable and abundant data and knowledge related to agriculture, natural resources, and food systems for scientists and stakeholders from different sectors and regions worldwide. It offers strong data support for promoting sustainable land, soil, and water resource management and achieving Zero Hunger. However, there is significant disparity in statistical survey capabilities among countries, with nearly 50% of countries lacking data that can be used for assessing progress toward Zero Hunger. Currently, seeking innovative technology and data has become one of the four key accelerators for implementing the 2030 Agenda and achieving FAO's Strategic Framework 2022–2031.

Over the past four years, this report has focused on innovating and implementing a series of Big Earth Data-enabled monitoring methods for indicators of meeting nutritional needs and ensuring sustainable food production, exploring ways of future upgrading and laying a solid foundation for the midterm progress assessment of SDG 2. This year, we continue to explore the monitoring of sub-indicators related to land and soil under Tier II SDG 2.4.1. Simultaneously, we will review and assess China's policies on sustainable land use for food production and evaluate their effectiveness. Based on these efforts, this chapter will conduct a global/China midterm progress assessment, providing scientific support to understand the global/China implementation process of SDG 2, identify issues and gaps, and improve and formulate acceleration strategies. It aims to provide a data foundation and experience for achieving SDG 2 in China and the rest of the world.

Midterm Progress

Based on the reports from 2019 to 2022 and the findings of this chapter, the localized progress evaluation was conducted of the nutritional health status of three indicators: prevalence of stunting among children (SDG 2.2.1), prevalence of overweight among children (SDG 2.2.2), and prevalence of anemia in women of reproductive age (SDG 2.2.3). The midterm progress of indicators such as proportion of agricultural area under productive and sustainable agriculture (SDG 2.4.1) globally and in China was assessed. The assessment based on Big Earth Data showed that although the global agricultural area has been increasing, the per capita cropland is continuously decreasing; on the basis of progress towards meeting nutritional needs, China is moving towards sustainable food production.

1. Regarding progress towards meeting nutritional needs (SDG 2.2.1, SDG 2.2.2 and SDG 2.2.3), the localized midterm progress study of China found that China has essentially achieved the expected results for these three indicators, including:

- The prevalence of stunting among children under six years of age (SDG 2.2.1) in China declined from 8.1% in 2013 to 4.8% in 2017. During the monitoring period, the prevalence rates in urban and rural areas decreased from 4.2% and 11.3% to 3.5% and 5.8% respectively. The decline in rural areas was more significant, narrowing the urban-rural gap.

- The prevalence of overweight among children under six years of age (SDG 2.2.2) in China showed a moderate decline, decreasing from 8.4% in 2013 to 6.8% in 2017. Specifically, the prevalence dropped from 8.4% to 6.9% in urban areas, and from 8.4% to 6.7% in rural areas, indicating a slower reduction in urban areas.

- The prevalence of anemia among women of reproductive age (SDG 2.2.3) in China also showed a moderate decline, decreasing from 15.0% in 2012 to 14.5% in 2018.

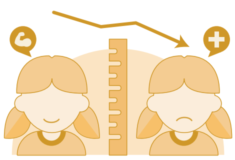
2. Regarding sustainable food production (SDG 2.4.1) , the global and China-scale monitoring of relevant sub-indicators was conducted in 2019, 2022, and during this chapter's research. It was found that global per capita cropland resources are becoming increasingly scarce.

- The total global agricultural land area showed a steady growth trend, with an annual increase of 52,600 km^2 from 2000 to 2015, which slowed down to 30,500 km^2 per year after 2015.

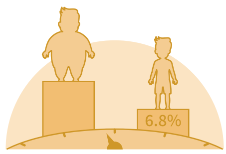
- In China, since 2000, the environmental impact per unit production has gradually decreased, and overall, land use has moved towards greater sustainability. As a practical approach to developing productive and sustainable agriculture (SDG 2.4.1), China has been implementing well-facilitated farmland construction since 2011. The area of such cropland increased from approximately 20% of the total cropland area in 2015 to over 50% in 2022, laying a solid foundation for establishing sustainable agricultural production systems. Evaluations of the well-facilitated farmland projects' effectiveness showed that resource use efficiency, including fertilizers, pesticides, irrigation water, and land, increased between 8.8% to 24.3%, with an average increase in practitioners' income of 56.4%.

- In terms of the sub-indicator related to soil under SDG 2.4.1, from 2015 to 2020, China's cropland topsoil organic carbon increased by 3.4%. Additionally, the cropland soil is projected to remain a carbon sink in the future, although the carbon sink intensity is decreasing. From 2015 to 2022, the area of terraced fields in China slightly increased. The existing terraced fields reduce the total soil water erosion of cropland in China by about 50%.

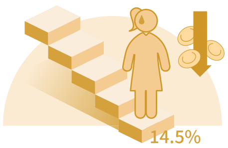
SDG 2 Zero Hunger: Global/China Midterm Progress



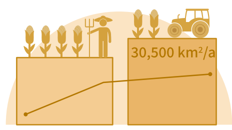
Prevalence of stunting among children under six years of age decreased to **4.8%** in 2017 in China[1].
SDG 2.2.1



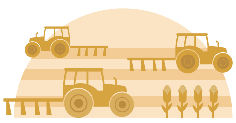
Prevalence of overweight among children under six years of age decreased to **6.8%** in 2017 in China[1].
SDG 2.2.2



Prevalence of anemia among women of reproductive age (age 18–44) decreased to **14.5%** in 2018 in China[1].
SDG 2.2.3



Annual growth rate of global cropland area dropped to **30,500 km^2/a** from 2015 to 2022[2].
SDG 2.4.1



Well–facilitated farmland accounted for over **50%** of China's total cropland in 2022[2].
SDG 2.4.1

China's farmland topsoil organic carbon increased **by 3.4%** between 2015 and 2020[3].
SDG 2.4.1

Terraced fields reduce soil water erosion of cropland in China by about **50%** in 2022[2].
SDG 2.4.1

Notes:
1.Report on Nutritional and Chronic Disease Status of Chinese Residents 2020;
2.Big Earth Data in Support of the Sustainable Development Goals (2023);
3.Big Earth Data in Support of the Sustainable Development Goals (2022).

Thematic Studies

Monitoring of Sustainable Food Production Systems

Cropland is a crucial resource for sustaining food production and forms the foundation for agricultural development. However, the utilization of cropland also has environmental implications, such as increased soil erosion risk compared to natural vegetation, especially in the absence of proper agricultural management measures. In this theme, we first conducted global-scale monitoring of cropland changes. Subsequently, we focused on one of the sub-indicators of SDG 2.4.1—soil erosion and degradation, and monitored the construction of terraced fields, a special soil conservation measure in China, and evaluated the effectiveness of terraced fields in mitigating soil erosion. Through these monitoring efforts, we continue to enrich the technical methods and data from Big Earth Data for monitoring and assessing Tier II indicators of SDG 2 Zero Hunger.

Global Monitoring and Evaluation of Cropland Changes

SDG 2.4: By 2030, ensure sustainable food production systems and implement resilient agricultural practices that increase productivity and production, that help maintain ecosystems, that strengthen capacity for adaptation to climate change, extreme weather, drought, flooding and other disasters and that progressively improve land and soil quality

Based on continuous time-series satellite observations, we established a coupled monitoring model to detect continuous change and dynamical update of cropland, enabling global monitoring of cropland dynamics at 30 m resolution from 1985 to 2022. Concurrently, in conjunction with global population statistics, we analyzed the per capita cropland availability at the national scale, providing scientific knowledge and data support for assessing food security in different countries.

From 1985 to 2022, the total global cropland area showed a stable growth trend, with a reduced annual growth rate of 30,500 km^2/a after 2015. Cropland is mainly concentrated in regions with flat terrain and relatively abundant rainfall, such as East Asia, South Asia, Europe, the North American Great Plains, and the La Plata Plain in southern South America (Figure 2-1). The increased cropland mainly occurred in Africa and South America, with South America experiencing extensive deforestation for cultivation, while Africa converting some previously unused land to cropland, resulting in an increase of 883,700 km^2 and 239,500 km^2 in cropland, respectively (Figure 2-2). The increase in cropland in Europe, North America, Asia, and Oceania was not significant, with increments of approximately 88,400 km^2, 8,800 km^2, 122,600 km^2, and 30,500 km^2, respectively, showing a markedly lower growth rate compared to the other two continents. Among them, some croplands in Eastern Europe has experienced abandonment, and some Asian countries have seen cropland being converted to construction land. In terms of temporal changes, South America and Africa had the highest increase in cropland, but their growth rates declined from 30,000 km^2/a and 7,300 km^2/a during 2000–2015 to 15,500 km^2/a and 5,700 km^2/a during 2015–2022, respectively.

The per capita cropland availability on a global scale has shown a declining trend, with the rate of decrease slightly reducing from 2015 to 2022, averaging 0.88% annually. Combining this with population statistics, we analyzed the per capita cropland availability from 1985 to 2022. The results indicated that the global per capita cropland availability decreased from 3.83 km^2 per 1,000 people in 1985 to 2.51 km^2 per 1,000 people in 2022, with an average annual decline of 0.93%. The rate of per capita cropland decrease slowed after 2015, reducing from 0.039 km^2 per 1,000 people per year during 1985–2015 to 0.023 during 2015–2022. Asia, with a high population density, has quite limited land resources per capita, with countries like Japan, Bangladesh, India, and China having less than 2.00 km^2 of cropland per 1,000 people. As the population continues to increase, per capita cropland availability in Asian countries is also showing a declining trend, with an annual decrease rate of 0.70% during 2015–2022.

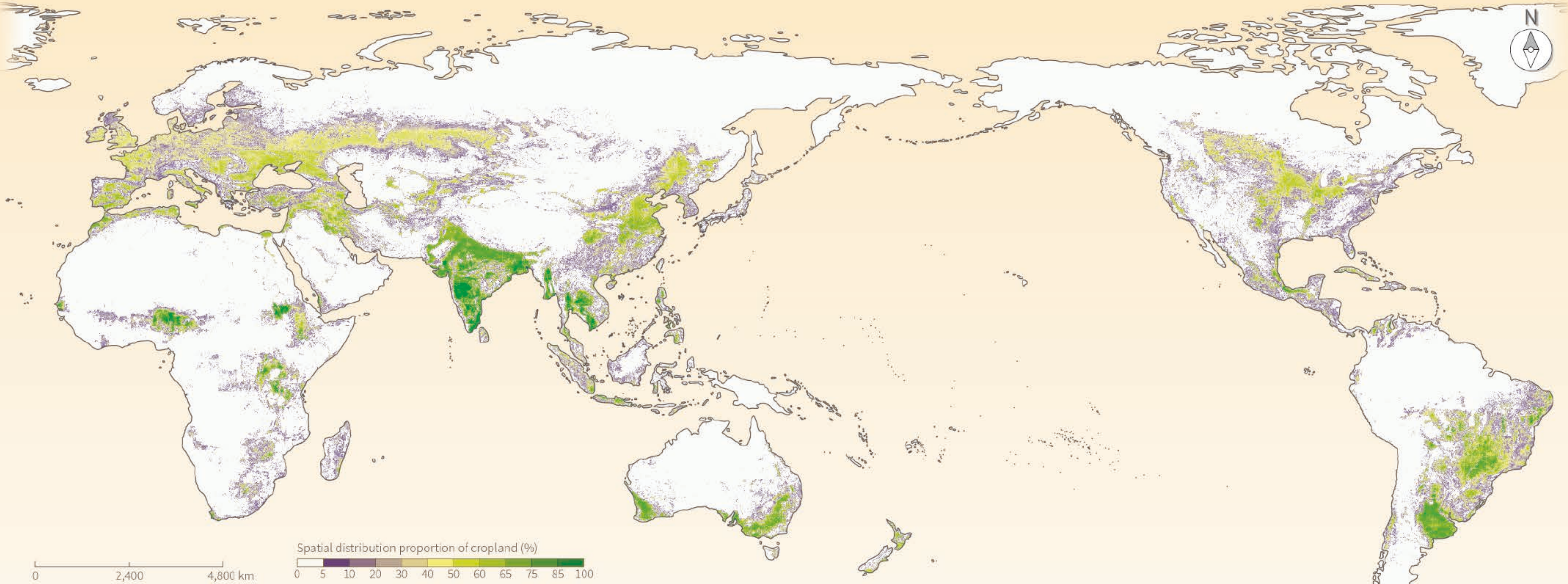


Figure 2-1

Global spatial distribution proportion of cropland area in 2022 (percentage of cropland area under 0.05 geographical grid)

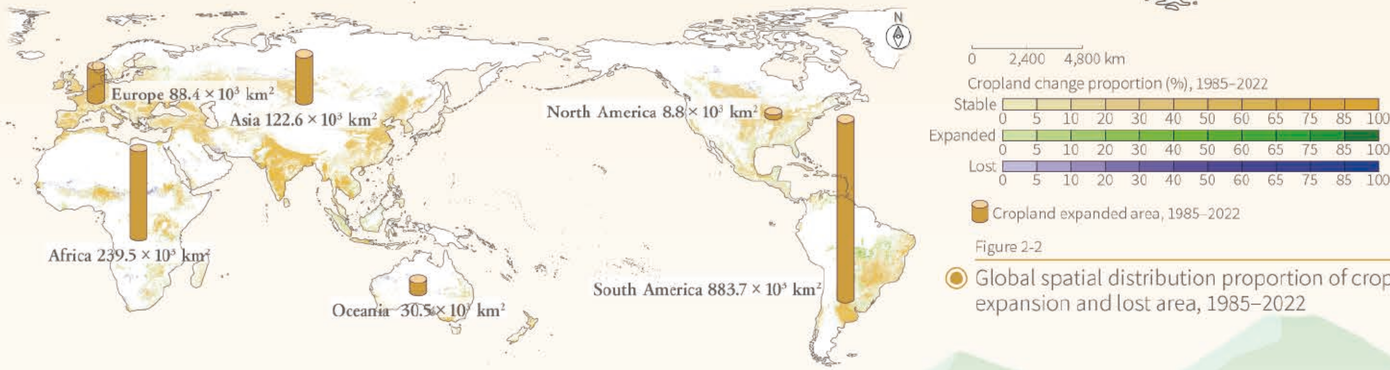


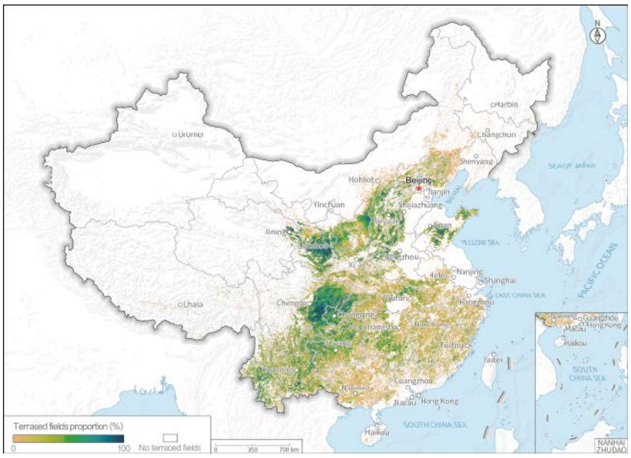
Figure 2-2

Global spatial distribution proportion of cropland expansion and lost area, 1985–2022

Distribution of Terraced Fields in China and Their Soil Conservation Benefits

SDG 2.4: By 2030, ensure sustainable food production systems and implement resilient agricultural practices that increase productivity and production, that help maintain ecosystems, that strengthen capacity for adaptation to climate change, extreme weather, drought, flooding and other disasters and that progressively improve land and soil quality

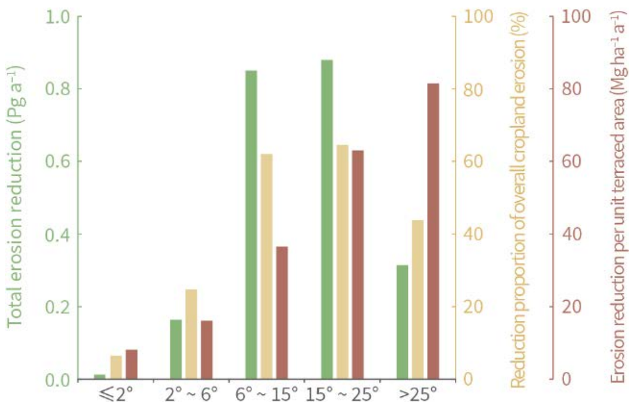
Terraced farming has been an important agricultural practice in China, given that approximately two-thirds of China's territory is covered by mountains (Wei *et al.*, 2016). Terraced fields not only ensure food production but also offer notable ecological benefits. In this section, we developed a new method based on remote sensing data for large-scale mapping of terraced field distribution in China. By utilizing remote sensing imagery and terrain data, we extracted multi-temporal spectral and topographic features, constructed optimized feature sets, obtained samples through interpretation and sample migration techniques, and designed appropriate classification algorithms. Consequently, we generated two sets of 30 m spatial resolution data depicting the distribution of terraced fields in China for the years 2015 and 2022. Furthermore, we evaluated the soil conservation benefits of terraced fields in China through developing a large-scale terraced field's soil conservation benefit evaluation model based on the Revised Universal Soil Loss Equation (RUSLE), which allowed us to quantify the soil erosion reduction benefits of terraced fields in China.



↑ Figure 2-3 Distribution map of terraced fields in China in 2022

Note: The pixel values in this figure represent the percentage of terraced fields within each 1 km × 1 km grid cell, calculated based on the results of the 30 m resolution terraced field mapping.

Terraced fields are widely distributed across China, accounting for about 1/4 of the national cropland area. From 2015 to 2022, about 46.7% of the newly added terraced fields were located in areas with slope gradients of 6° to 15°. The spatial distribution of terraced fields in China is closely related to its topography, with primary concentrations in plateau mountainous regions (e.g., the Loess Plateau, the Yungui Plateau), hilly regions (e.g., the central and southeastern hills), and mountain-basin transition regions (e.g., the eastern Sichuan Basin) (Figure 2-3). The provinces with higher proportions of newly added terraced fields from 2015 to 2022 were mainly located in areas with numerous and dense pre-existing terraced fields, such as Gansu and Shaanxi on the Loess Plateau of northwestern China, and Sichuan and Yunnan in southwestern China. About 46.7% of the newly added terraced fields were located in areas with slope gradients of 6° to 15°. The conversion of sloping land to terraces in areas with high slope gradients plays a positive role in mitigating soil erosion resulting from improper land utilization.



↑ Figure 2-4 Water erosion reduction benefits of terraced fields in areas with different slope gradients

The soil conservation benefits of terraced fields in China are significant, and the existing terraced fields can reduce the total water erosion of cropland in China by about 50%. The benefits of terraced fields exhibit spatial heterogeneity. Terraced fields demonstrate particularly significant soil conservation benefits in agricultural regions dominated by mountainous and hilly landscapes. In southwestern and northwestern China, where both terraced field coverage and potential erosion rates are high, terraced fields contribute most to erosion reduction. In the eastern and southern hilly regions of China, terraced fields also show considerable erosion reduction benefits per unit terrace area. In regions with fewer terraced fields and lower potential erosion amount per unit terrace area, such as the northeastern region, the soil erosion reduction benefits of terraced fields are relatively low. The existing terraced fields can reduce the total water erosion of cropland in China by about 50%. In the areas with slope gradients ranging from 6° to 25°, terraced fields lead to the greatest reduction in cropland erosion in terms of both total amount reduction and percentage reduction. In the areas with slope gradients greater than 25°, terraced fields demonstrate the largest erosion reduction per unit terrace area. The results indicates that terraced fields play a crucial role in soil conservation on steep-slope cropland.

Evaluation of Sustainable Food Production Policies and Benefit

Cropland is the foundation for food production. Food security relies on safeguarding the productive capacity of cropland. China has implemented the strategy of "ensuring food production through sustainable cropland use and innovative agricultural technology," forging a distinctive path for cropland utilization and protection. With only 7% of the world's cropland, China feeds about 20% of the global population, achieving remarkable accomplishments. This theme systematically examines China's policies and systems related to cropland protection and utilization. It also conducts a comprehensive assessment of the effectiveness of the well-facilitated farmland construction, aimed at productive and sustainable agriculture, showcasing China's approach to ensuring food security and promoting sustainable development.

China's Cropland Utilization and Protection Policies and Experience Sharing

SDG 2.3: By 2030, double the agricultural productivity and incomes of small-scale food producers, in particular women, indigenous peoples, family farmers, pastoralists and fishers, including through secure and equal access to land, other productive resources and inputs, knowledge, financial services, markets and opportunities for value addition and non-farm employment

SDG 2.4: By 2030, ensure sustainable food production systems and implement resilient agricultural practices that increase productivity and production, that help maintain ecosystems, that strengthen capacity for adaptation to climate change, extreme weather, drought, flooding and other disasters and that progressively improve land and soil quality

The method of literature analysis and historical analysis was employed to search, organize, and summarize the relevant policies in the field of cropland utilization and protection in China. The main content and development process of these policies were introduced, and a complete timeline of the history of cropland protection was created, showcasing China's experience in cropland protection and ensuring food security.

From the historical evolution of cropland protection and utilization, China has gone through three important development stages after an initial period of experimentation: the "stage of land development and utilization" focusing on quantity, the "stage of simultaneous emphasis on quantity and quality" for cropland protection and utilization, and the "stage of a new tripartite pattern, integrating quantity, quality, and ecology." In response to the issues in cropland protection, utilization and management, China continuously adjusted and improved specific policy measures, achieving comprehensive upgrades in the concept, system, measures, methods, and entities of cropland protection and utilization. These upgrades include: 1) Conceptual upgrade, from focusing on "quantity" to "quantity + quality," and further to the "tripartite management of quantity + quality + ecology"; 2) System upgrade, raising hierarchical levels from "national policy to basic national policy, then to lifeline, and finally red line"; 3) Measures upgrade, transitioning from simple "protection and utilization" to a comprehensive system of "controls, construction and incentives for protection and utilization,"; 4) Methods upgrade, evolving from solely administrative measures to a combination of administrative, economic, and engineering measures, supported by a plethora of technical means; 5) Entity upgrade, shifting from a single governing entity (the government) to a composite and diversified governing entity (including the government, society, and farmers), effectively promoting the integration and refinement of cropland utilization and protection.

Overall, the development stages of cropland protection and utilization in China reflect the country's progression from extensive utilization to transformative protection and utilization, and further to high-quality protection and utilization.

Land use survey, farmland grading, well-facilitated farmland construction and other practical measures have been taken to implement cropland sustainable utilization and protection policies. Starting from 1984, China successively issued technical regulations such as *Technical Guidelines for Land Use Survey, National Land Classification (Trial Implementation), Land Use Classification, Regulations for Farmland Grading and Regulations for Farmland Valuation,* and conducted three large-scale surveys on land use at the national level, which provided information on the quantity, quality distribution, and dynamic changes of cropland. With the demarcation of "three spaces and three lines" and the formulation and implementation of national spatial planning, farmland preservation quantity and permanent basic farmland protection area and other targets were established as rigid indicators, and the responsibility assessment of cropland protection and food security is implemented. Relying on the comprehensive monitoring and supervision platform for natural resources that covers the five layers of "space, sky, ground, people, and network", a grid-based supervision system covering five levels, namely national, provincial, municipal, county, and township, was established to implement cropland protection responsibilities in terms of area and location.

In recent years, China has embarked on the construction of well-facilitated farmland, which refers to farmland that is equipped with modern infrastructure, technology, and management practices to enhance its productivity, sustainability, and efficiency. This initiative covers eight aspects: land, soil, water, roads, forest, electricity, technology, and management, and corresponds to several sub-indicators of SDG 2.4.1, and is an essential measure for China's development of productive and sustainable agriculture. The area increased from approximately 20% of the total cropland area in 2015 to over 50% in 2022 (Figure 2-5). The per mu (approximately 0.067 hectares) production of the well-facilitated farmland generally increased by 10%–20%, providing significant support for the national grain output to stay above 6.5×10^{11} kilograms for years running. At present, well-facilitated farmland projects are being documented and put under the digitized management. An information management platform for land consolidation is established to achieve the unification of "land, data, and records," thus providing assurance for better construction and management of well-facilitated farmland and for achieving sustainable agricultural development.

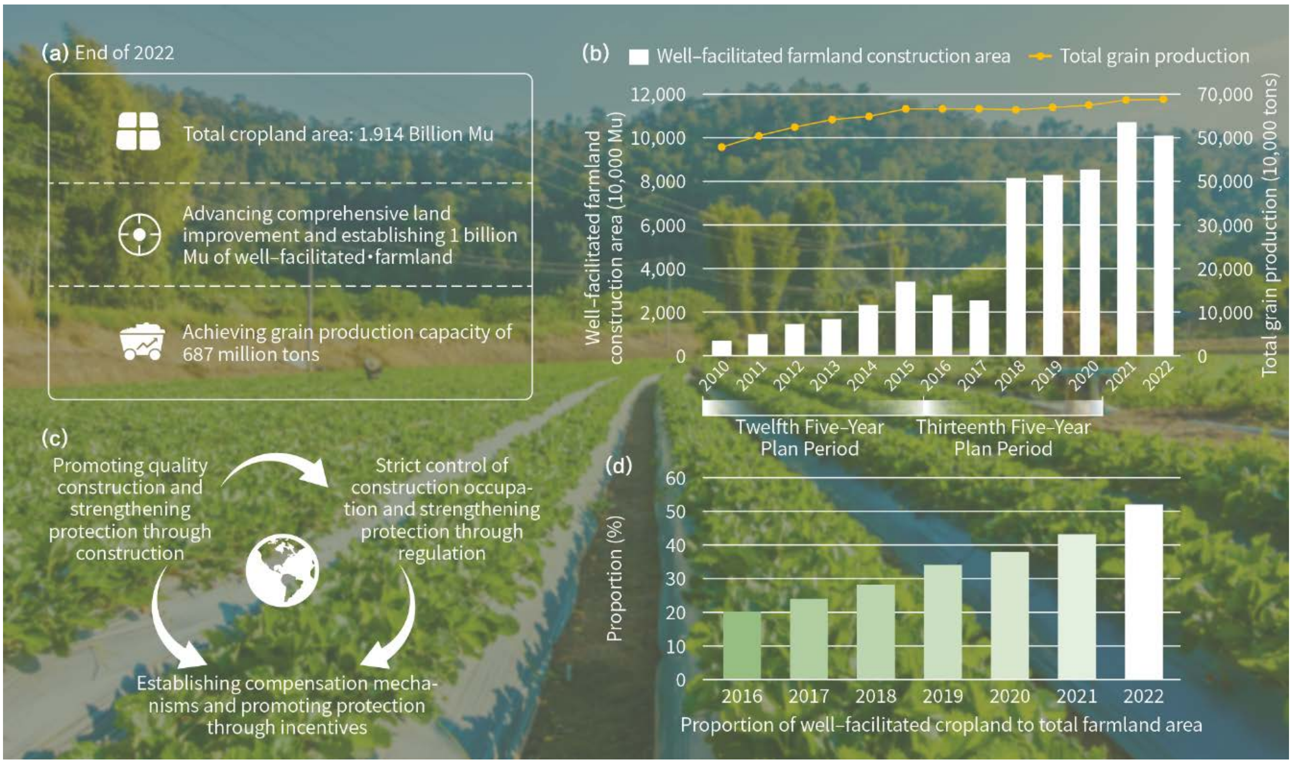


Figure 2-5 Statistical analysis of effectiveness of cropland utilization and protection

Evaluation of China's Cropland Construction Benefits

SDG 2.3: By 2030, double the agricultural productivity and incomes of small-scale food producers, in particular women, indigenous peoples, family farmers, pastoralists and fishers, including through secure and equal access to land, other productive resources and inputs, knowledge, financial services, markets and opportunities for value addition and non-farm employment

SDG 2.4: By 2030, ensure sustainable food production systems and implement resilient agricultural practices that increase productivity and production, that help maintain ecosystems, that strengthen capacity for adaptation to climate change, extreme weather, drought, flooding and other disasters and that progressively improve land and soil quality

Well-facilitated farmland construction is an important measure adopted in recent years for sustainable utilization and protection of farmland in China. By the end of 2022, China had cumulatively completed the construction of one billion mu (6.67×10^7 hectares) of well-facilitated farmland capable of producing stable high yield and resistant to drought and flood, ensuring a grain production capacity of over one trillion catties (approximately 5×10^{11} kilograms) and guaranteeing 80% of China's total grain output. In this case, a three-terminal metric method was constructed based on the spectral mixture decomposition model for substrate, vegetation and dark matter to monitor farmland production capacity. A Bayesian model was integrated to form a competitive learning mechanism, focusing on typical areas implementing well-facilitated farmland projects, identifying changes in farmland production capacity and the timing of significant variations, and achieving dynamic monitoring of farmland production capacity before and after the construction of well-facilitated farmland. Additionally, on-site investigations were carried out in key agricultural areas across the country to comprehensively assess the effects of well-facilitated farmland construction, contributing Chinese experience to the achievement of SDG 2.4.

The monitoring of well-facilitated farmland productivity revealed that from 2010 to 2022, 87% of well-facilitated farmland in the typical areas experienced increased productivity, with an average increase of 16% per mu. Farmland productivity monitoring based on ground observation data indicated that from 2010 to 2022, in the selected typical region (Jiangsu), 87% of the well-facilitated farmland witnessed a significant increase in productivity (Figure 2-6). Despite frequent extreme weather events in recent years, most well-facilitated farmland in the region

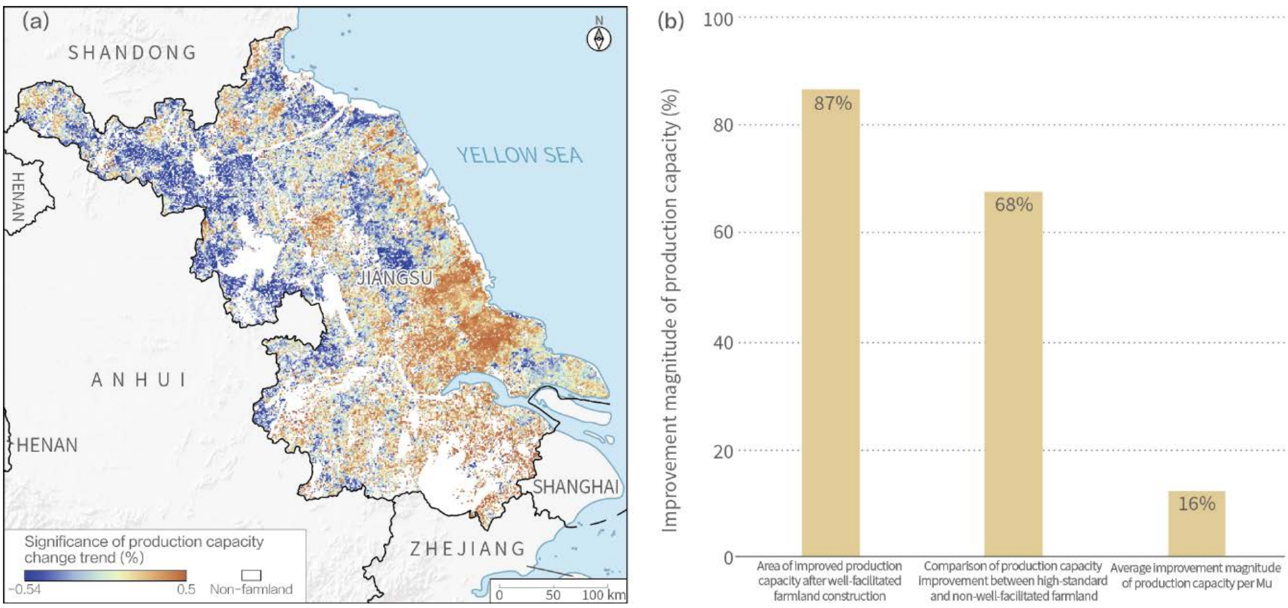
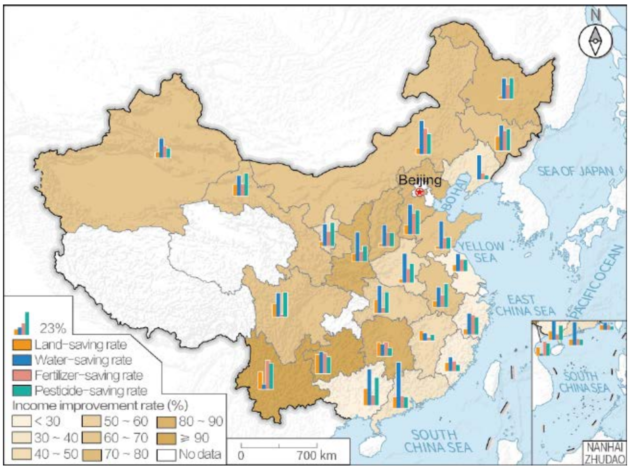


Figure 2-6 Distribution characteristics of farmland production capacity changes in Jiangsu, a typical well-facilitated farmland region. (a) Distribution of significance of farmland production capacity changes in Jiangsu; (b) Improvement range of well-facilitated farmland and comparison with non-well-facilitated farmland

achieved "five hundred kilograms for one season, and a ton of grain for two seasons," reflecting the improved disaster resilience of well-facilitated farmland. When excluding climate impacts, a comparison of productivity between well-facilitated farmland and non-well-facilitated farmland areas showed that 68% of well-facilitated farmland patches exceeded the productivity of non-well-facilitated farmland, with an average increase of 16% per mu. For example, in Danyang, southern Jiangsu, 578,900 mu (38,600 hectares) of well-facilitated farmland have been constructed, accounting for 75.4% of the total cropland area of the city, with grain production per mu increased by more than 80 catties (40 kilograms). Overall, the construction of well-facilitated farmland can effectively promote stable and increased grain production on cropland.

After the implementation of the well-facilitated farmland projects, the efficiency of resource utilization, including fertilizers, pesticides, irrigation water and land, increased by 8.8%–24.3%. The income of practitioners significantly improved, with an average increase of 56.4%. The projects also led to a noticeable improvement in the scientific level of farming, resulting in a significant enhancement of comprehensive agricultural benefits. In the project areas, while reducing the cost of resource inputs, it also reduced agricultural non-point source pollution, saving land, water, fertilizer and pesticide per mu by 8.8%, 24.3%, 13.8%, and 19.1%, respectively, promoting low-consumption, high-efficiency, ecological, and safe sustainable agriculture.

Furthermore, the implementation of the well-facilitated farmland projects greatly boosted the appropriate expansion of producing and operating entities. Each hectare of land could lead to an average increase of CNY 7,464 in farmers' income, with an average increase rate of 56.4%. 77.3% of the project areas met the target of achieving an average increase of CNY 3,000 per hectare in farmers' income (Figure 2-7). There are three main reasons for the increase in farmers' income: first, during the construction of well-facilitated farmland, local farmers contributed their labor and efforts and received corresponding remuneration; second, after the construction of well-facilitated farmland, there is an increase in the crop value of the land, due to expanded sales channels as a result of improved transport convenience; third, the added benefits brought about by the well-facilitated farmland construction are enjoyed by the locals through dividends obtained through land transfer or land shareholding, and at the same time, higher productivity releases more people from farming for higher-paying jobs.



↑ Figure 2-7 Provincially assessed efficiency gains from well-facilitated farmland in China's key agricultural regions in saving land, water, fertilizer, pesticide and farmer income increase

The comprehensive benefits of well-facilitated farmland construction show significant regional differences. In terms of land saving rate, the southwest region, characterized by fragmented and less leveled farmland, has shown significant improvement, with Guizhou's land saving rate increasing by 18.5%, and Yunnan experiencing an increase of CNY 7,080 or 63.0% in land rental per hectare.

The effectiveness of fertilizer and pesticide saving is most pronounced in the southeast and southwest regions, where the terrain is more undulating and farmland is more fragmented, achieving gains of 18%–24%. In comparison, the Yangtze River middle and lower reaches region has the lowest fertilizer saving rate at 8.0%, and the northeast region has the lowest pesticide saving rate at 12.8%.

Regarding water saving rate, the arid and semi-arid region of Inner Mongolia has achieved a water saving rate of 33.6%, with an average reduction of 1,621.5 m^3 in irrigation water per hectare. In the southeast region, Guangdong has reached a water saving rate of 45.9%.

The southwest region stands out in terms of land saving rate and income increase rate, reaching 17.9% and 95.8%, respectively. Almost all project areas (96.2%) have seen an average increase in net farmer income per hectare of over CNY 3,000.

2 ZERO HUNGER

Recommendations and Outlook

This chapter focuses on two main themes: the monitoring and evaluation of sustainable food production systems and the related policies and their benefits. It continues to innovate and explore the use of Big Earth Data-enabled monitoring methods for SDG 2.4.1 (proportion of agricultural area under productive and sustainable agriculture), where methods have been available but data was previously lacking. It also reviews and summarizes China's policies in promoting productive and sustainable agriculture and evaluates their overall effectiveness. Based on this foundation, this chapter summarizes the results of the past four years' case studies, and details a midterm evaluation. The findings show that China has been moving towards sustainable food production while gradually meeting nutritional needs.

Based on this research, we propose the following recommendations:

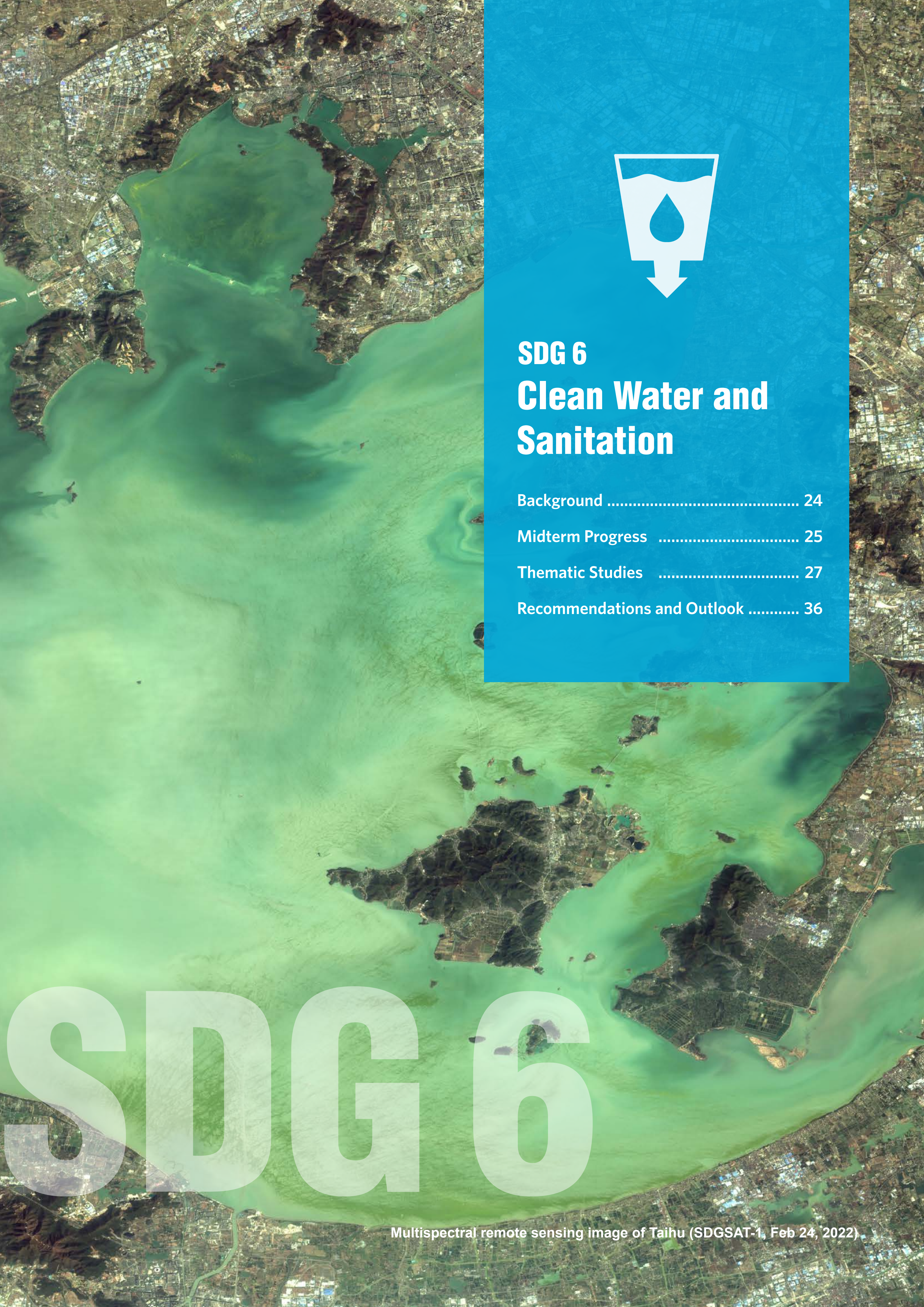
1. Cropland is the foundation of agricultural development, and soil fertility preservation and enhancement are essential for ensuring food production. Terraced field, as a special type of cropland, plays a crucial role in soil protection in hilly and mountainous areas. In the future, there should be further reforms in the management system of cropland protection and utilization, with multiple stakeholders such as the central government, local governments, and ordinary farmers, implementing a comprehensive management system comprising "monitoring, incentives, and regulation." Satellite remote sensing and drone technology should be utilized to establish a regularly updated monitoring system, incorporating various measures for soil protection into agricultural statistics and land spatial planning. Additionally, reward and incentive mechanisms primarily based on different types of subsidies for soil fertility preservation and enhancement should be trialled.

2. Well-facilitated farmland construction, as an important measure in China's development of productive and sustainable agriculture, aims primarily to increase grain productivity but also to promote farmers' income, resource efficiency, and emission reduction. It serves as a typical demonstration for achieving high-quality and sustainable agricultural development. Given that multiple factors can drive up cropland productivity, future planning should be based on regional characteristics, further strengthening the rational distribution of well-facilitated farmland and setting synergistic objectives. Cooperation efforts should be intensified in improving soil quality and agricultural technological services to enhance the comprehensive benefits of synergistic objectives in cropland utilization.

3. Looking ahead to the 2025 comprehensive review, and drawing on the experience of continuous SDG 2 indicators monitoring, the following modification suggestions are proposed for the Zero Hunger indicators: Firstly, to better evaluate the achievement of Zero Hunger, food waste should be included as an indicator for SDG 2 just like food demands. Secondly, SDG 2.4.1 has always been in a state of lacking data despite having methods, due to certain extent to the fact that it is defined based on statistical surveys. Hence, appropriate adjustments should be made to the indicator definition to allow for monitoring using a wider range of data types. Thirdly, different countries/regions choose different age ranges when evaluating the nutritional health status of their residents. For example, when calculating the nutritional health status indicators such as the prevalence of stunting and the prevalence of overweight among Chinese children, the age range is usually under six years, and the age range of the prevalence of anemia among Chinese women of reproductive age is usually 18-44 years old. It is suggested that when evaluating the nutritional health status of residents in different countries/regions, consideration be given to the differences in age selection among countries/regions as well as the consistency of evaluation indicators. Instead of defining specific age groups, relevant social activities can be used to distinguish them, such as children of preschool age and women of childbearing age, so as to enhance the actual comparability and availability of indicator data in different regions.

In the future, we will continue to explore the capabilities of Big Earth Data in monitoring and evaluating food security and zero hunger, providing scientific evidence for pathways to achieve SDG 2.

SDG 6
Clean Water and Sanitation



Multispectral remote sensing image of Taihu (SDGSAT-1, Feb 24, 2022)

SDG 6 CLEAN WATER AND SANITATION

Background

As we approach the halfway point of the 2030 Agenda, fundamental changes have yet to be achieved in the development and utilization of water resources. Issues such as extensive and inefficient utilization, poor management, excessive extraction, and pollution of freshwater and groundwater resources are persisting. Globally, water-related ecosystems are deteriorating at an alarming rate, and the progress towards the Clean Water and Sanitation Goal (SDG 6) is not on track as planned, a situation globally recognized (UN, 2023b). The United Nations' *Sustainable Development Goals Report 2022* revealed that due to a lack of monitoring, the quality of the water resources relied upon by at least 3 billion people for survival remains unknown, and 730 million people are living in countries facing severe water scarcity. At the current pace, by 2030, an estimated 1.6 billion people, 2.8 billion people, and 1.9 billion people will still lack access to safe drinking water, sanitation facility, and basic handwashing facility, respectively. Progress needs to quadruple in implementing the indicators of safe drinking water, sanitation, and hygiene facilities if they are to be achieved by 2030 (UN, 2022).

While global progress towards SDG 6 is assessed based on national statistics, it is insufficient to support policy-making and decision-making at various levels of government below the national level. In recent years, non-traditional data sources such as satellite remote sensing data, mobile phone data, and crowdsourced data have been providing valuable supplements to traditional statistical data. For instance, the rapid development of Big Earth Data technology has significantly improved the monitoring and evaluation capabilities for SDG 6. These technological means enable high spatiotemporal resolution monitoring of relevant indicators through remote sensing, regular revisits, and rapid information extraction, leading to more accurate and objective assessment results while saving costs and time (Lu *et al*., 2021).

Over the past four years, the report has conducted a series of case studies on global, regional, Chinese, and provincial scales to monitor and evaluate the progress on SDG 6. These research findings have laid a solid foundation for conducting midterm progress reviews at different scales. This year, we will combine these achievements to carry out midterm progress reviews at the global and Chinese scales. The aim is to provide scientific support for understanding the progress of SDG 6 implementation at these two levels, identifying issues and gaps, and providing scientific evidence for making improvements and acceleration strategies. The evaluations will also contribute data basis and experiential references to achieving SDG 6 at the global and Chinese scales.

Midterm Progress

Based on the two reports of 2021 and 2022 and the research findings of this report, an understanding of the midterm progress has been formed concerning global-scale improvements in water environment, enhanced water use efficiency, changes in aquatic ecosystems, and China-scale achievements in safe drinking water, sanitation facilities, improved water environment, enhanced water use efficiency, integrated water resources management, and changes in aquatic ecosystems. The results show that from 2000 to 2022, the transparency of large lakes and reservoirs showed a clear overall increasing trend, the water-use efficiency in cropland significantly increased, and the distribution range of lakes and reservoirs expanded. From 2015 to 2021, China made notable progress towards SDG 6, with SDG 6.1.1 and SDG 6.3.1 having been realized, while other indicators still face varying degrees of challenges.

1. In terms of safe drinking water (SDG 6.1), China's capacity to provide safe drinking water (SDG 6.1.1) has significantly improved. From 2015 to 2021, the surface water sources meeting the water quality safety standards in China increased by 3.5 percentage points, with 96.1% of the surface water sources meeting the safety standards in 2021.

2. Regarding sanitation and hygiene (SDG 6.2), the condition of sanitation facilities in China (SDG 6.2.1a) has significantly improved. From 2015 to 2020, the growth rate of the number of public toilets per 10,000 urban residents was 11.2%.

3. In terms of improving the water environment (SDG 6.3), the reports of 2021 and 2022, as well as the research of this report, show significant improvements in China's surface water and groundwater environments, and stability in overall quality of groundwater. From 2015 to 2020, the number of sewage treatment plants in China increased from 4,300 to 9,100, with a growth rate of 111.6%. The sewage treatment capacity (SDG 6.3.1) increased from about 171 million tons/day to about 267 million tons/day, with a growth rate of 56.1%. From 2015 to 2020, 26 provinces in China saw an increase in the proportion of surface water bodies with good water quality (SDG 6.3.2). From 2001 to 2022, 41.4% of the large lakes and reservoirs globally showed a significant increase in transparency, while only 11.3% showed a significant decrease in transparency.

4. In terms of improving water-use efficiency (SDG 6.4), the 2021 and 2022 reports, as well as the research in this report, show that from 2001 to 2020, there was a clear upward trend in the water-use efficiency of cropland in agricultural areas worldwide, with an increase of 3.5%. From 2001 to 2019, China's agricultural water-use efficiency (SDG 6.4.1) significantly improved, with wheat, corn, and rice water-use efficiency (crop yield/evapotranspiration) increasing by 33.4%, 20.0%, and 14.1%, respectively. From 2015 to 2020, China's overall water stress level (SDG 6.4.2) showed a declining trend, decreasing from 66% to 58%, indicating a moderate level of water stress.

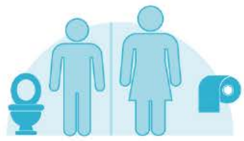
5. In terms of integrated water resources management (SDG 6.5), the 2021 report showed that China had made remarkable progress in improving the level of integrated water resources management, with the comprehensive evaluation score for SDG 6.5.1 increasing from 75 points in 2017 to 79 points in 2020, reaching the medium-high level globally.

6. Regarding the protection and restoration of water-related ecosystems (SDG 6.6), the 2021 and 2022 reports, as well as the research in this report, show that from 2001 to 2021, the water surface area of lakes and reservoirs increased at a rate of 719.1 km^2/a globally. From 2015 to 2020, both natural and artificial water areas in China showed an increasing trend, with the water surface area of reservoirs increasing by approximately 7%. Compared to the period from 2005 to 2014, the rate of decline in China's groundwater storage from 2015 to 2020 slowed down by 65%. Compared to the period from 2010 to 2015, the rate of loss of marsh wetlands in China from 2015 to 2020 slowed significantly, down from 4.1% to 0.8%.

SDG 6 Clean Water and Sanitation: Global/China Midterm Progress

From 2015 to 2021, the surface water sources meeting the water quality safety standards in China increased by 3.5 percentage points, with **96.1%** of the surface water sources meeting the safety standards in 2021[1].

SDG 6.1.1



Growth rate of the number of public toilets per 10,000 urban residents in China was **11.2%** from 2015 to 2020[1].

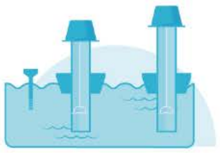
SDG 6.2.1a

The number and capacity of wastewater treatement plants increased by **111.6%** and **56.1%** respectively in China from 2015 to 2020[2].

SDG 6.3.1

41.4% of large lakes and reservoirs globally showed a significant upward trend in transparency from 2001 to 2022[1].

SDG 6.3.2



26 Chinese provinces witnessed an improvement in the proportion of surface water with good quality from 2015 to 2020; overall quality of groundwater was stable from 2019 to 2021[3].

SDG 6.3.2

Cropland water-use efficiency in agricultural areas worldwide increased by **3.5%** from 2001 to 2020[1].

SDG 6.4.1

Water-use efficiency of wheat, corn, and rice in China increased by **33.4%**, **20.0%**, and **14.1%**, respectively, from 2001 to 2019[3].

SDG 6.4.1

Overall water stress level in China decreased from 66% to **58%** from 2015 to 2020[3].

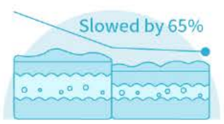
SDG 6.4.2

China's comprehensive score for integrated water resources management increased from 75 in 2017 to **79** in 2020[2].

SDG 6.5.1

Global lakes and reservoirs showed an increase of **719.1 km²/a** in area from 2001 to 2021[1].

SDG 6.6.1



Natural and artificial water bodies in China increased in area, with reservoir water surface area growing by about **7%** from 2015 to 2020[3]; comparing 2015–2020 with 2005–2014, the rate of decrease in groundwater storage in China slowed by **65%**[3], and wetland loss rate in China reduced from 4.1% to **0.8%**[2].

SDG 6.6.1

Notes:

1.Big Earth Data in Support of the Sustainable Development Goals (2023); 2.Big Earth Data in Support of the Sustainable Development Goals (2021); 3.Big Earth Data in Support of the Sustainable Development Goals (2022).

Thematic Studies

Safe Drinking Water and Sanitation

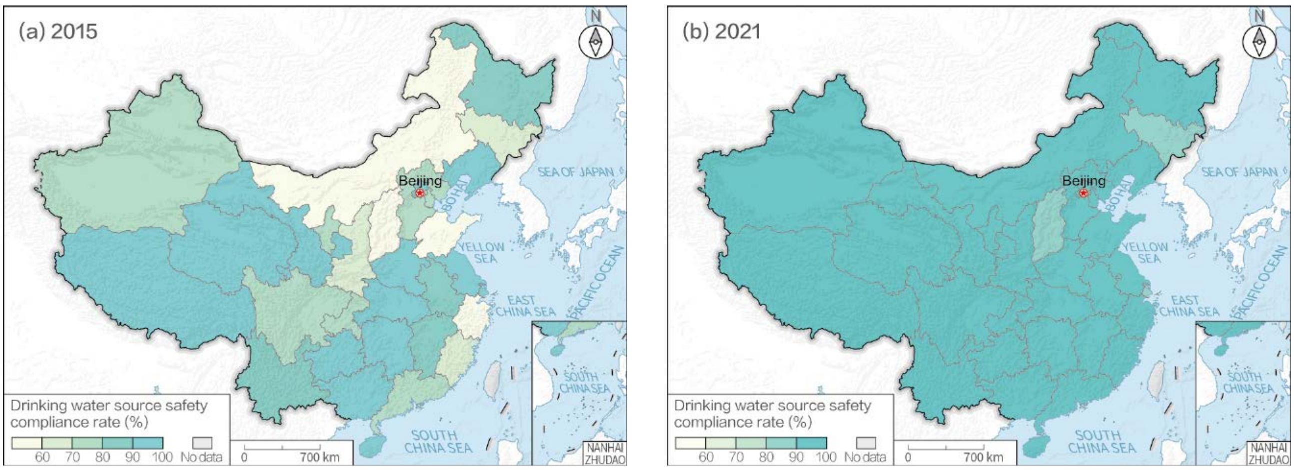
Safe drinking water and sanitation facilities are directly related to the life and health of the general population. The *Healthy China 2030 Blueprint* promulgated in 2016, clearly stated the need to "bring drinking water sources up to safety standards and strengthen groundwater management and protection," which has effectively promoted the improvement of China's drinking water safety. In recent years, China has made significant progress in public health services through the implementation of the "Toilet Revolution," with a substantial increase in the number of public toilets and a significant expansion in coverage to serve a wider population.

Assessment of Water Quality Monitoring in China's Drinking Water Sources

SDG 6.1: By 2030, achieve universal and equitable access to safe and affordable drinking water for all

The compliance rate of Chinese centralized urban drinking water surface water sources at or above the prefecture level was 92.6% in 2015 and 96.1% in 2021, with an increase of 3.5 percentage points. In this case, the comprehensive compliance rates of surface water sources for drinking water in the 31 provinces (autonomous regions, municipalities directly under the central government, excluding Hong Kong, Macau, and Taiwan) were calculated using the Spearman's rank correlation coefficient, based on the location of automatic monitoring stations and real-time online water quality data for drinking water sources in China in 2015 and 2021, and data from the *Report on the State of the Environment in China 2015* and *Report on the State of the Ecology and Environment in China 2021.* The growth rates of each province from 2015 to 2021 were evaluated, where the growth rate = (2021 indicator value - 2015 indicator value) / 2015 indicator value × 100%.

In 2021, 28 provinces (autonomous regions, municipalities directly under the central government) in China achieved a compliance rate of more than 90% in the water quality safety of surface drinking water sources. Compared to 2015, compliance rate in the water quality safety of surface drinking water sources for each province (autonomous regions, municipalities directly under the central government) in 2021 has significantly improved. Among them, Inner Mongolia had the highest growth rate in compliance, indicating the most significant improvement in water quality of its drinking water sources, followed by Shandong and Zhejiang (Figure 3-1). The rapid increase in compliance rate is attributed to a series of water environment governance and protection policies, such as the *Water Pollution Prevention and Control Action Plan* formulated and implemented by the Chinese government since 2015.



↑ Figure 3-1 Spatial distribution map of compliance rate in water quality safety of surface drinking water source in China, 2015–2021

Monitoring the Proportion of Population Covered by Public Sanitation Facilities in China

SDG 6.2: By 2030, achieve access to adequate and equitable sanitation and hygiene for all and end open defecation, paying special attention to the needs of women and girls and those in vulnerable situations

Based on data from the *China Statistical Yearbook* and the *China Urban and Rural Construction Statistical Yearbook*, an analysis was conducted on the change in the number of urban public toilets and the number of public toilets per 10,000 people in China for the years 2015 and 2020. Seven typical cities were selected from the seven major administrative regions of China. Utilizing data on land use, Digital Elevation Model (DEM), Points of Interest (POI), high-resolution population distribution, etc., a monitoring model was developed to assess the proportion of the population covered by public sanitation facilities in these cities. The model calculated the proportions in these seven cities for the years 2015 and 2020, and further validated the statistical results of public sanitation facility services.

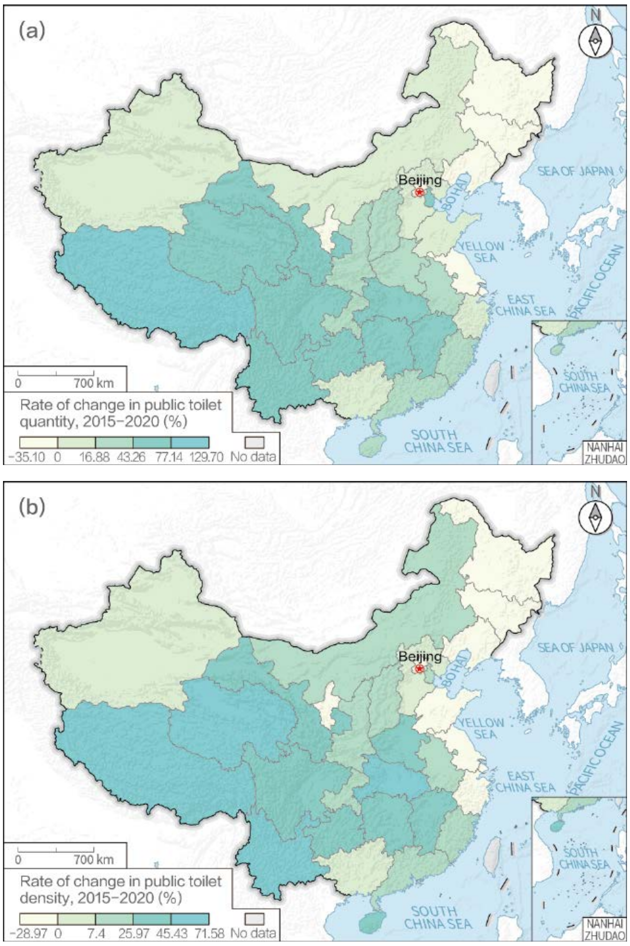


Figure 3-2 Change rates in the total number of urban public toilets and the number of public toilets per 10,000 urban residents in China, 2015–2020. (a) Change rates in total number of urban public toilets; (b) Change rates in number of public toilets per 10,000 people

From 2015 to 2020, the number of urban public toilets in China increased by 22.1%, and the number of public toilets per 10,000 people increased by 11.2%. In 2015 and 2020, the number of urban public toilets in China was 324,949 and 396,617, respectively, and the number of public toilets per 10,000 people was 4.0 and 4.5, respectively. In terms of changes, from 2015 to 2020, the number of public toilets and the number of public toilets per 10,000 people decreased to some extent in the northeastern region, some provinces in the eastern coastal region, and Ningxia. However, the other provinces showed varying degrees of increase. Among them, Xizang had the highest growth rates in the number of public toilets and the proportion of the population covered, reaching 129.7% and 71.6%, respectively (Figure 3-2).

In 2015 and 2020, the proportion of the population covered by public toilets in seven typical cities in China increased from 19.0% to 28.7%. According to POI data, the total number of public toilets in these seven cities increased from 10,472 to 27,686 from 2015 to 2020, with varying degrees of improvement in toilet accessibility for the population in all seven cities (Figure 3-3). Among them, Qinhuangdao showed the highest increase in public toilet accessibility for the population, reaching 781.8%. These monitoring results reflect the significant achievements of the "Toilet Revolution" implemented in China in recent years.

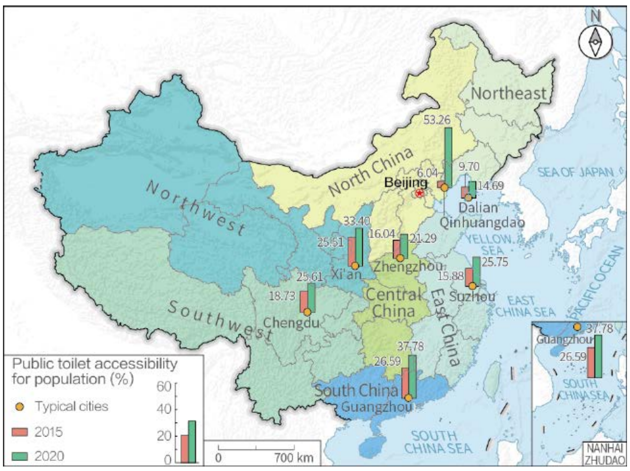


Figure 3-3 Spatial distribution of public toilet accessibility for urban residents in typical Chinese cities, 2015–2020

Improving Water Environment

Currently, satellite remote sensing data is becoming the most important and cost-effective source of data for surface water quality monitoring. While filling data gaps, its advantages of large-scale and long-term dynamic monitoring provide an effective approach to achieving global surface water quality monitoring and tracing long-term spatiotemporal changes.

Spatiotemporal Change in Transparency of Global Large Lakes and Reservoirs

SDG 6.3: By 2030, improve water quality by reducing pollution, eliminating dumping and minimizing release of hazardous chemicals and materials, halving the proportion of untreated wastewater and substantially increasing recycling and safe reuse globally

Using the 500 m resolution Moderate Resolution Imaging Spectroradiometer (MODIS) surface reflectance data (MOD09A1) for the period 2000–2022, as well as measured transparency data set of Chinese surface water bodies, data sets from the Chinese National Earth System Science Data Center and Chinese Lake Science Database, European Multi Lake Survey (EMLS) shared data set, and AquaSat shared data set from the United States, also using the transparency inversion model of surface water bodies, based on the Forel-Ule Index (FUI) and hue angle α (Wang *et al.*, 2020), and the MODIS surface reflectance data for the summer season in both the northern and southern hemispheres, we constructed a data set of transparency for 1,117 large lakes and reservoirs worldwide with areas greater than 25 km^2. Based on this data set, we analyzed the spatiotemporal trends of transparency in these large lakes and reservoirs.

The overall transparency of large lakes and reservoirs globally follows a concave distribution with latitude. Lakes and reservoirs in high-latitude regions near the poles have higher transparency, with an average transparency of around 4 m, while those in low-latitude regions around the equator and up to latitudes of 20° have lower transparency, with an average transparency of less than 1 m. Looking at the average transparency of large lakes and reservoirs across different continents, those in Asia and Europe have higher transparency, while those in Africa have the lowest transparency. In terms of average transparency across different climatic zones globally, lakes and reservoirs in polar and cold temperate regions have higher transparency, while those in tropical regions have lower transparency (Figure 3-4).

Since 2000, there has been a clear overall upward trend in the transparency of large lakes and reservoirs worldwide. Approximately 41.4% of large lakes and reservoirs show a significant increase in transparency ($p<0.05$), while only 11.3% exhibit a significant decrease in transparency ($p<0.05$) (Figure 3-5). Looking at the statistics from each continent, the average annual change rate of lake and reservoir transparency is positive for all six continents. Among them, the average transparency changes in Asia and Africa are relatively modest, with an average change rate of 1.3 cm/a. In contrast, Europe demonstrates a significant increase in transparency, with an average change rate of 7.6 cm/a.

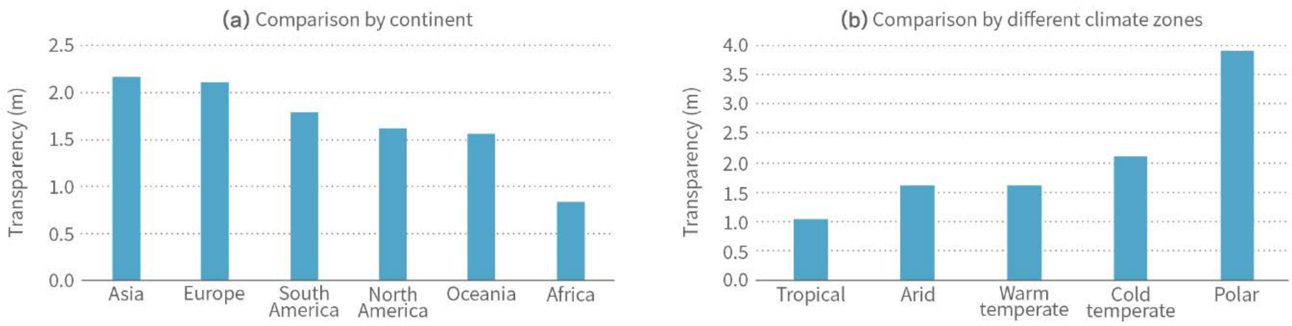


Figure 3-4 A comparison of the average transparency and the number of large lakes/reservoirs in different continents and climate zones from 2000 to 2022

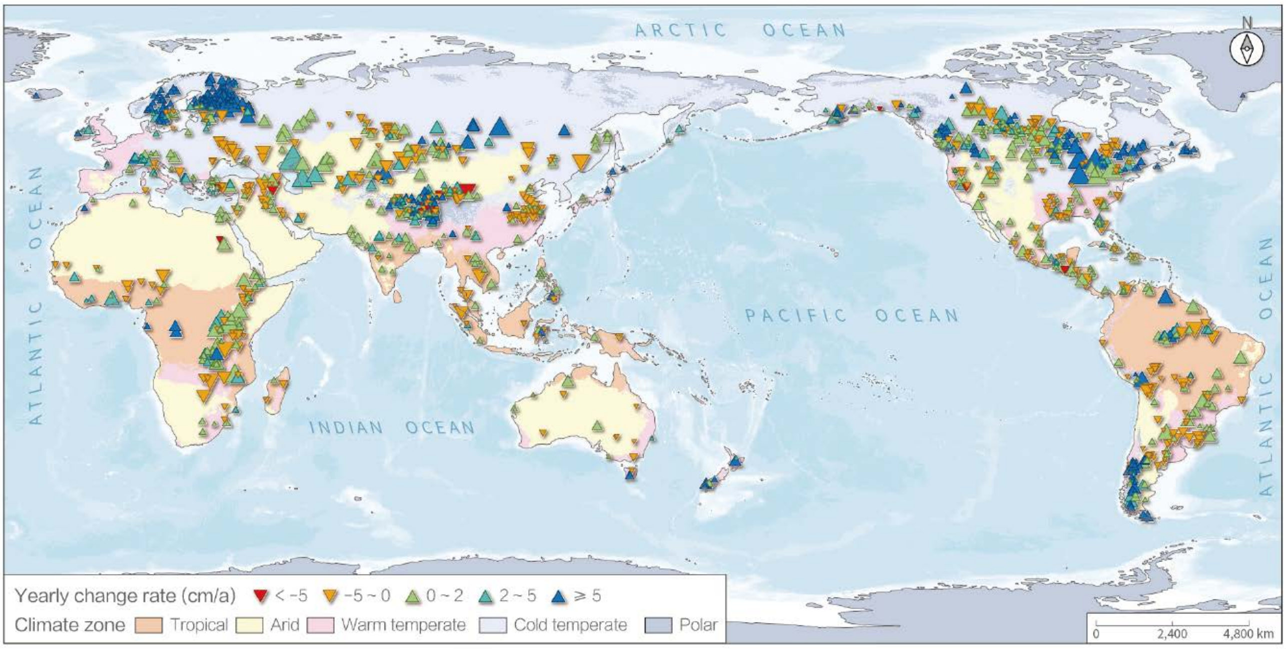


Figure 3-5 Distribution of large lake and reservoir transparency change rates worldwide from 2000 to 2022

Improving Water-Use Efficiency

Improving water-use efficiency across various industries has always been a topic of great concern, closely related to human well-being and Sustainable Development Goals. Agriculture consumes a large amount of water, especially for evapotranspiration, making it crucial to enhance agricultural water-use efficiency as an important measure for achieving sustainable development and utilization of water resources.

Global Cropland Water-Use Efficiency Changes

SDG 6.4: By 2030, substantially increase water-use efficiency across all sectors and ensure sustainable withdrawals and supply of freshwater to address water scarcity and substantially reduce the number of people suffering from water scarcity

In this report, cropland water-use efficiency was defined as the ratio of Net Primary Productivity (NPP) to water consumed by evapotranspiration of cropland. Based on the global 1 km resolution annual dataset of cropland water-use efficiency from 2001 to 2020, we analyzed the spatiotemporal changes in global cropland water-use efficiency in terms of distribution and interannual variation, and assessed the changes and improvements in cropland water-use efficiency at the global, regional, and country scales.

From 2001 to 2020, there was a significant increasing trend in cropland water-use efficiency in agricultural areas worldwide, with an overall rise of 3.5%. However, spatial differences were observed. At the continental scale, differences were evident. Asia had the largest increase in cropland water-use efficiency (8.9%), followed by Oceania (7.2%). North America also showed an increasing trend, but with lower rates (4.6%) compared to Asia and Oceania. Europe, Africa, and South America had relatively small changes in cropland water-use efficiency (all less than 1%) (Figure 3-6).

From 2001 to 2020, the cropland water-use efficiency of the world's major grain-producing countries showed an upward trend. India, with a relatively low average cropland water-use efficiency, had the highest increase at 19.8%, followed by Canada at 18.2%, and China at 13.3%. Indonesia, Brazil, and France, with higher average cropland water-use efficiency, had smaller increases, all below 2%. The United States and Argentina had increases of 3.2% and 2.6%, respectively (Figure 3-7).

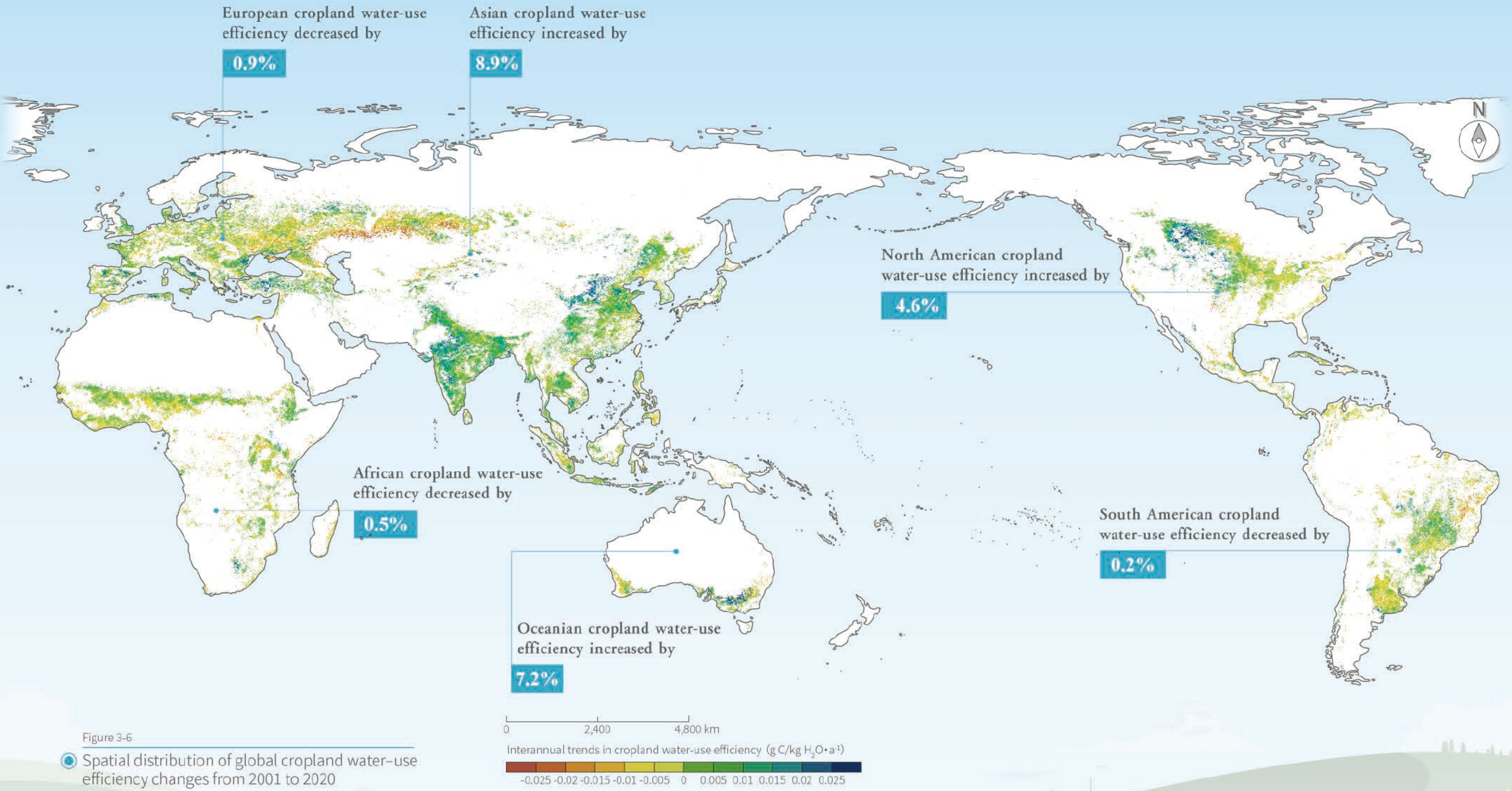


Figure 3-6

Spatial distribution of global cropland water-use efficiency changes from 2001 to 2020

The significant improvement in China and India is attributed to the much larger increase in cropland NPP (both over 25%) compared to the increase in evapotranspiration (approximately 10%). This improvement is mainly due to factors such as advances in agricultural technology (e.g., field management, water-saving measures, fertilization, breeding, etc.), adjustments in cropping structure and intensity, and climate change (e.g., elevated carbon dioxide concentration, etc.) (Chen *et al.*, 2019; Yang *et al.*, 2022; Zhai *et al.*, 2021).

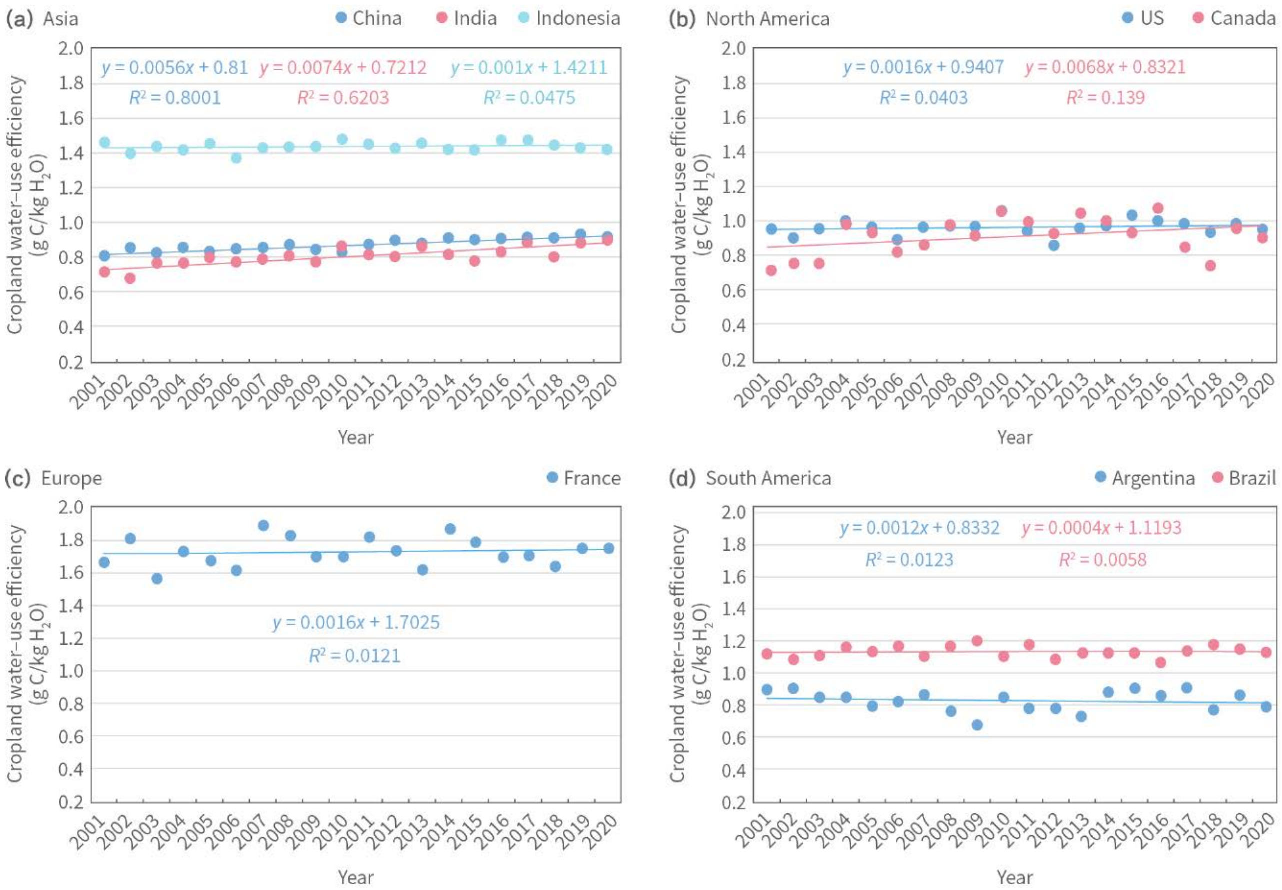


Figure 3-7 Annual variation of cropland water-use efficiency from 2001 to 2020 in the major grain-producing countries worldwide

Changes in Water Ecosystems

According to the latest assessment report by the United Nations (UN, 2022), water-related ecosystems worldwide are degrading at an alarming rate. In the past five years, nearly one-fifth of the global river basins have experienced significant changes in surface water area, including the addition of new water bodies due to floods and reservoir construction, as well as the disappearance of lakes, wetlands, and floodplains due to drought (UNEP, 2021b). Satellite remote sensing technology enables precise monitoring and quantification of global and regional surface and groundwater dynamics.

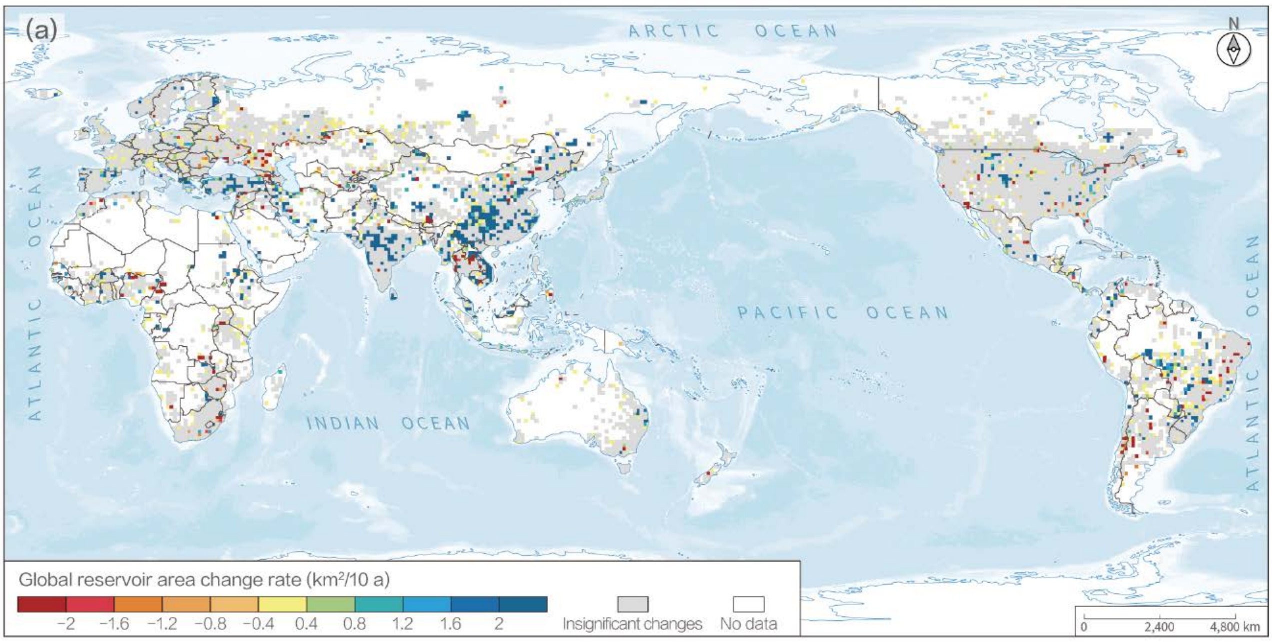
Surface Water Area Changes of Global Natural Lakes and Reservoirs

SDG 6.6: By 2020, protect and restore water-related ecosystems, including mountains, forests, wetlands, rivers, aquifers, and lakes

Using the Global Surface Water (GSW) data set from the European Commission's Joint Research Centre (JRC) (Pekel *et al.*, 2016) as the data source, a spatial statistical overlay technique was employed to obtain global-scale water occurrence (referring to the proportion of observations classified as water to the total number of valid observations during a given period, reflecting the frequency of water presence over the entire historical period) maps for each three-year period from 2001 to 2021. The maps were then overlaid with the Global Lakes (GLAKES) data set (Pi *et al.*, 2022) and different global-scale reservoir data sets (Donchyts *et al.*, 2022; Wang *et al.*, 2021) for analysis to construct a time-series data set of lake and reservoir areas weighted by water occurrence at different time periods. Based on this data set, the trends and spatial variations in natural lake and reservoir surface water area changes were analyzed.

From 2001 to 2021, **the global coverage of natural lake and reservoirs showed an overall expansion trend, with an area change rate of 719.1 km^2/a.** Among them, reservoirs exhibited continuous and significant expansion, with a change rate of 1133.5 km^2/a. On the other hand, natural lakes showed a trend of initial shrinkage, followed by expansion, and then shrinkage again, with a slight overall decline, and a change rate of -414.4 km^2/a (Figure 3-8).

At the continental scale, except for South America, the global reservoir surface water area has shown an



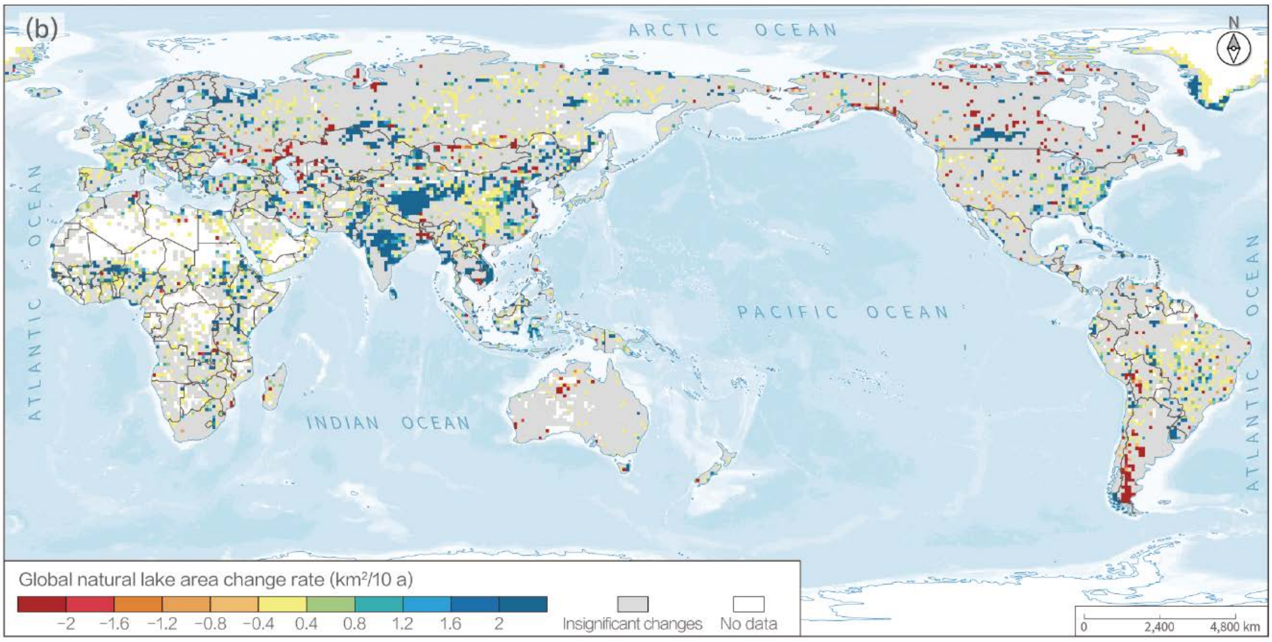


Figure 3-8 Spatial-temporal pattern of surface water area change trend for global natural lakes and reservoirs over the 2001–2021 period (1° × 1°). (a) Global spatial-temporal pattern of changes in reservoir water area; (b) Global spatial-temporal pattern of changes in natural lake water area

Note: The gray color indicates that the inter-annual change rate of water body extent in that grid is not statistically significant.

increasing trend in the past 20 years, with Asia (835.4 km^2/a) and Africa (187.4 km^2/a) exhibiting significant expansion. At the national scale, the reservoir surface water area has significantly increased in 46 countries, while only seven countries show a significant decreasing trend. The primary countries and regions displaying expansion trends include China, Russia, Southeast Asian (Vietnam, Laos, Cambodia, Myanmar, Malaysia), India, Pakistan, Iran, Türkiye, Northeast Africa (Sudan, Ethiopia), and Canada. On the other hand, the countries and regions with shrinking trends are mainly concentrated in Brazil, Argentina, Thailand, Iraq, Ukraine, and Southern Africa (South Africa, Zambia, Zimbabwe).

Regarding natural lakes, no significant interannual changes have been observed on a continental scale. However, at the national level, the lake surface water area has significantly expanded in 68 countries, while 12 countries show a significant shrinking trend. Countries or regions with expansion trends include China, Southeast and South Asian (India, Pakistan, Myanmar, Indonesia), Iraq, Germany, the central and northwest part of Africa (Mali, Nigeria, Democratic Republic of the Congo, Ethiopia, Kenya, etc.), the western coast of South America (Chile, Ecuador), and Greenland. On the other hand, countries or regions with shrinking trends are primarily located in Central and Western Asia (Kazakhstan, Uzbekistan, Turkmenistan, Iran, Afghanistan), Ukraine, Southeast Africa (Madagascar, Mozambique, Malawi), Australia, the United States, Canada, and central and southern South America (Argentina, Bolivia).

Changes in Groundwater Storage in Africa

SDG 6.6: By 2020, protect and restore water-related ecosystems, including mountains, forests, wetlands, rivers, aquifers and lakes

This study utilized spherical harmonic coefficients data from the Gravity Recovery and Climate Experiment (GRACE) satellites (2003–2017) and GRACE Follow-On satellites (2018–2022), Global Land Data Assimilation System (GLDAS) and Catchment Land Surface Model (CLSM) v2.2 simulation data, and GLobal HYdrogeology MaPS (GLHYMPS) v2.0. The researchers employed a coordinated forward model that fused both satellite and model data (Pan *et al.*, 2017) to calculate the groundwater storage changes in Africa at monthly and 0.5° resolution, represented in terms of equivalent water height. Furthermore, the study combined this data set with precipitation data from the Global Precipitation Climatology Centre (GPCC) to analyze the patterns of groundwater storage changes in Africa and the influencing factors.

From 2003 to 2022, significant (p<0.05) increases and decreases in groundwater storage in Africa were observed in regions covering approximately 33% and 36% of the continent's area, respectively. The overall change rate was determined to be 1.84 ± 0.58 mm/a. Among these regions, the areas with significant increases showed a change rate of 8.91 mm/a, while the areas with significant decreases exhibited a change rate of -3.58 mm/a.

Overall, the change in groundwater storage in Africa exhibits a roughly symmetrical pattern with the Equator as the center (Figure 3-9). Specifically, the low-latitude regions (10º S to 15º N) show an overall increase, while the mid-latitude regions (10º to 25º S, 30º to 40º N) show an overall decrease. In particular, the groundwater storage in the area north of the Sahara Desert (-3.84 mm/a), the Congo River Basin (-2.22 mm/a), the Zambezi River Basin (-4.76 mm/a), and Madagascar Island (-19.30 mm/a) are significantly decreasing. On the other hand, the groundwater storage in the Niger River Basin (8.36 mm/a), the East African Highlands (30.58 mm/a), and some other regions are showing a significant increasing trend.

Changes in precipitation are the main driving factors behind the variations in groundwater storage in Africa. Generally, when statistically analyzed longitudinally and latitudinally, there is a good consistency between changes in groundwater storage and precipitation, reflecting the dominant role of precipitation changes at the regional

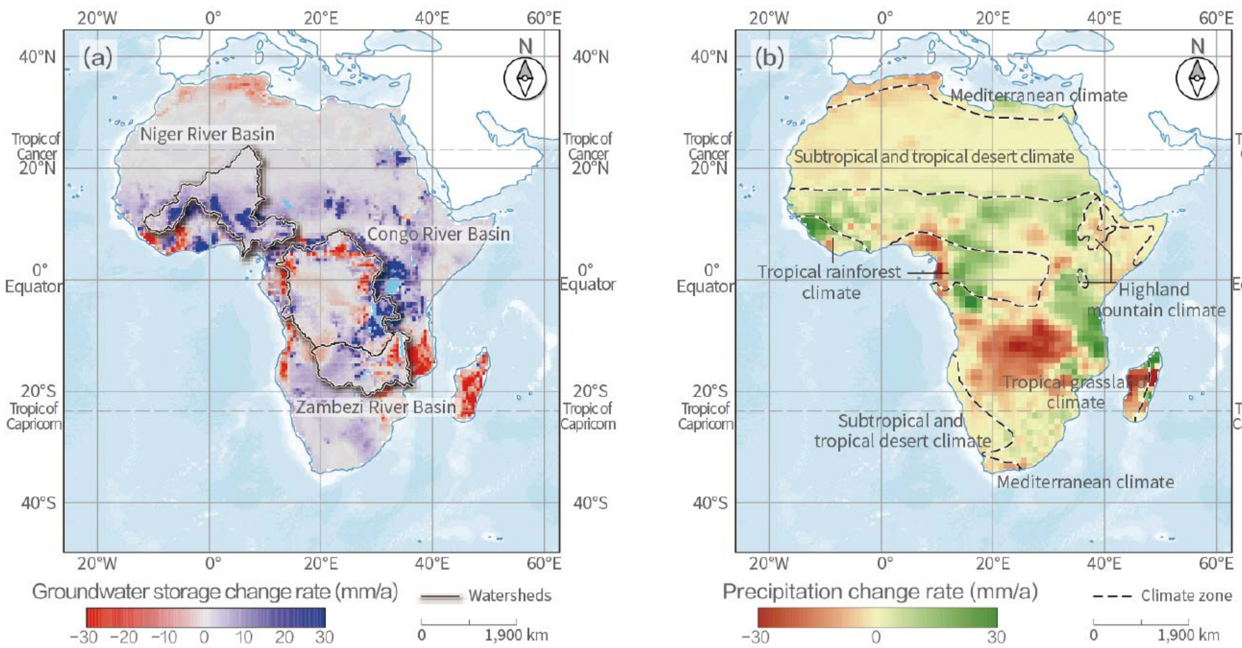


Figure 3-9 Spatial distribution of groundwater storage change rate and precipitation change rate in Africa, 2003–2022. (a) Groundwater storage change rate; (b) Precipitation change rate

scale. This consistency is more evident in the north-south direction due to the spatial distribution of climate zones. However, at the local scale, there are certain differences between changes in groundwater storage and precipitation, indicating the superposition of other factors at the local scale. For example, in the southern part of West Africa with a tropical grassland climate, although precipitation is decreasing at a rate of -9.89 mm/a, factors such as expansion of farmland together with increased surface water irrigation contribute to an increase in groundwater storage at a rate of 9.20 mm/a. Furthermore, it is worth noting that reduced precipitation in some regions may intensify human reliance on groundwater and subsequently increase groundwater consumption. For instance, in the area north of the Sahara Desert influenced by the Mediterranean climate, precipitation is decreasing at a rate of -4.24 mm/a, and in this context, increases in agricultural irrigation and water wells contribute to a decrease in groundwater storage at a rate of 3.84 mm/a.

Recommendations and Outlook

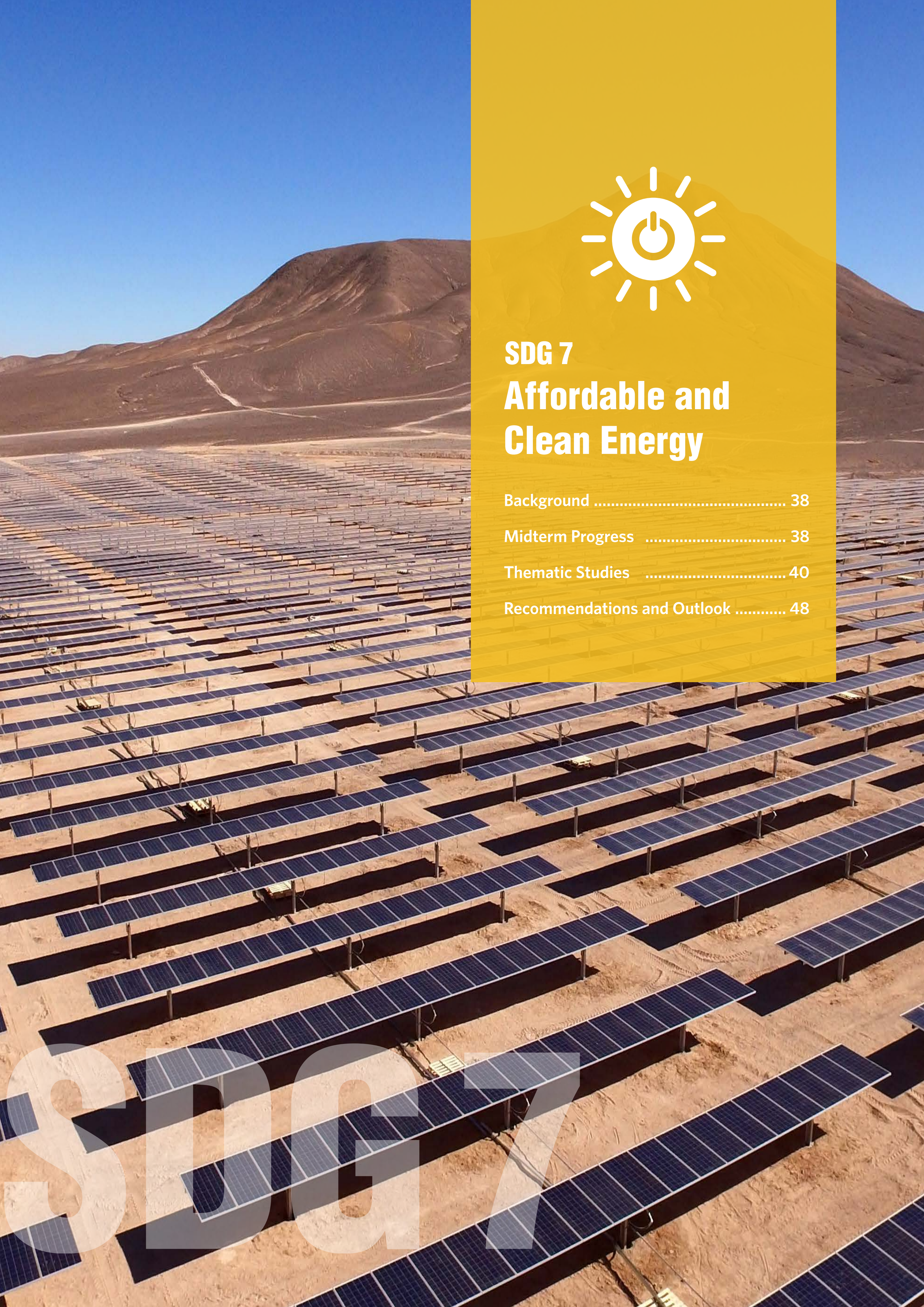
In this chapter, thematic case studies were conducted on safe drinking water and sanitation facilities in China, global water environment improvement and water-use efficiency, and the changes in the scopes of global and African water-related ecosystems over time. Combined with the results of case studies conducted over the past two years using Big Earth Data technology, we summarized the midterm progress on SDG 6 at global, regional, and Chinese scales. We found that the transparency of global large lakes and reservoirs and cropland water-use efficiency show an overall increasing trend, while the distribution range of global lakes and reservoirs is expanding, and the groundwater storage in Africa exhibits an overall upward trend; China has made significant progress towards SDG 6 as a whole, but the achievement of targets and indicators shows regional disparities and still faces challenges to varying degrees.

Based on the research in this chapter, we propose the following recommendations:

1. To ensure the continuous compliance of China's drinking water quality standards, comprehensive management should be carried out in the watersheds where water sources are located. In rural and remote areas where the health conditions are unknown, it is necessary to strengthen the collection and sharing of statistical survey data to accurately understand the current situation of sanitation facilities and formulate improvement policies.

2. When conducting assessments of changes in surface water environment, water use-efficiency, and water ecosystems at the global and regional scales over different periods and in different areas, it is essential to make extensive use of continuous and distributed satellite remote sensing data products to overcome the inadequacy of statistical survey data to detect significant changes and, consequently, the inability to inform targeted improvement policies.

In the future, in order to achieve precise monitoring and assessment of water resources supply and utilization, water environment management and protection, and water ecosystems restoration and sustainability at the global, regional, national, and local scales, and to inform decision-making, the existing targets and indicators of SDG 6 may be improved and adjusted. This includes strengthening the statistical survey work for social indicators such as SDG 6.1.1, SDG 6.2.1, SDG 6.3.1, SDG 6.5.1, and SDG 6.5.2 to ensure the representativeness and timeliness of data; and promoting the Big Earth Data-enabled standardized data production for environmental indicators such as SDG 6.3.2, SDG 6.4.1, SDG 6.4.2, and SDG 6.6.1.



SDG 7

Affordable and Clean Energy

Background

At the midpoint for the 2030 Agenda, certain progress has been made on various indicators under SDG 7 Affordable and Clean Energy. For instance, SDG 7.1.1, the global proportion of population with access to electricity, increased from 87% in 2015 to 91% in 2020. SDG 7.1.2, the proportion of the global population using clean cooking fuels, rose from 64% in 2015 to 71% in 2021. SDG 7.2.1, the share of global renewable energy installed capacity, grew from 29.5% in 2015 to 40.2% in 2022 (IRENA, 2023). SDG 7.3.1, global energy intensity per unit of Gross Domestic Product (GDP) (in terms of purchasing power parity), decreased from 5.0 MJ/USD in 2015 to 4.6 MJ/USD in 2020 (IEA *et al*., 2023). However, the growth rates of these indicators are significantly lagging behind schedule, making it challenging to achieve the overall SDG 7, "ensuring access to affordable, reliable, sustainable, and modern energy for all" by 2030. At the current rate of progress, it is estimated that by 2030, 660 million people globally will still lack access to electricity (IEA, 2022a), and 1.9 billion people will be unable to access clean cooking fuels (IEA *et al*., 2023). To achieve the Goal, the annual growth rate for SDG 7.1.1 needs to increase from the current 0.5 percentage point to 0.9 percentage point, and the energy efficiency improvement rate for SDG 7.3 must be doubled.

To achieve SDG 7 by 2030, it is urgent for the global community to increase and coordinate investments in funds, technologies, and policies. In 2021, China proposed the Global Development Initiative and actively assisted developing countries in implementing the 2030 Agenda through the Global Development and South-South Cooperation Fund and China-United Nations Peace and Development Fund. Initiatives such as the Sustainable Development Satellite Constellation Program have been undertaken to develop and share SDG monitoring reports and data products, thereby enhancing the tracking and monitoring capacity of SDG 7 indicators on a global scale. Currently, Big Earth Data technologies represented by satellite remote sensing and geographic information systems have filled the gaps in traditional statistical and survey data due to their ability to periodically obtain global data, making them increasingly important as a data source and analysis tool for global sustainable development research.

Accurate assessment of the midterm progress on SDG 7 forms the basis for policy-making in the latter half of SDG 7 implementation. The 2022 report completed global/China monitoring and assessment of SDG 7 progress, covering aspects such as access to electricity (SDG 7.1.1), renewable energy (SDG 7.2), energy efficiency improvement (SDG 7.3), and international energy cooperation (SDG 7.a/SDG 7.b), laying a solid foundation for midterm progress evaluation of SDG 7. Building on the work of the previous year, the 2023 report focuses on monitoring clean cooking fuels (SDG 7.1.2), and further supplements the assessment of global wind and solar resources, China's clean energy transition, and China's international energy cooperation in the field of renewable energy and international energy cooperation. Based on the work of the past two years, this chapter conducted a comprehensive evaluation of global/Chinese midterm progress towards SDG 7, providing scientific support to understand the progress, identify issues and gaps, and improve and formulate strategies for accelerating the implementation. It also serves as a data foundation and reference for achieving SDG 7 globally and in China.

Midterm Progress

Based on the 2022 report and the research results of this chapter, a midterm assessment of global/Chinese progress towards SDG 7 was conducted, including access to electricity (SDG 7.1.1), clean cooking (SDG 7.1.2), renewable energy (SDG 7.2), energy efficiency improvement (SDG 7.3), and international energy cooperation (SDG 7.a/SDG 7.b). The evaluation based on Big Earth Data indicates that out of the six indicators of SDG 7, the global electrification area has been seen significant progress, and China has achieved complete electrification. All the other five indicators have also shown notable advancements. The specific progress is as follows:

1. In terms of global access to electricity (SDG 7.1.1), the research from the 2022 report showed that the global electrified built-up areas increased significantly from 2014 to 2020, with an increase of 29,108.62 km^2. The proportion of electrified built-up areas in the world increased from 96.95% to 98.68%. Among them, 117 countries/regions saw an increase in the proportion of electrified built-up areas, while 32 countries/regions experienced a decrease. Built-up areas yet to be electrified are mainly located in Africa and Asia,

with 76% of the 20 countries with the largest proportions of unelectrified built-up areas located in Sub-Saharan Africa. China achieved complete access to electricity in 2015.

2. Regarding clean cooking fuels (SDG 7.1.2), China's population relying on clean cooking energy and technology reached 83.55% in 2022, with about 150 million people still not using clean cooking energy. Gas and electricity are the primary cooking energy sources in China.

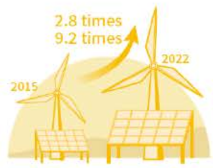
3. In terms of renewable energy (SDG 7.2), China has made significant progress in wind, solar, and other renewable energy sources, as well as in electric energy substitution in the transport sector. By 2022, China's wind and photovoltaic installed capacity increased by 2.8 times and 9.2 times, respectively, compared to 2015. The proportion of renewable energy generation in China's total electricity generation rose from 24.5% in 2015 to 31.3% in 2022. The number of new energy vehicles in China grew from nearly 580,000 in 2015

SDG 7 Affordable and Clean Energy: Global/China Midterm Progress

Global electrified built-up area increased by nearly **2%** from 2014 to 2020[1].
SDG 7.1.1

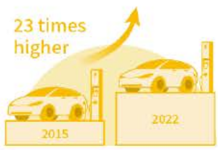
China achieved **complete access to electricity** in 2015[1].
SDG 7.1.1

Proportion of population relying on clean fuels and technology reached **83.55%** in China in 2022[2].
SDG 7.1.2



Wind and solar installed capacity in China was **2.8** times and **9.2** times higher in 2022 compared to 2015[2].
SDG 7.2.1

Wind and solar electricity generation in China was **5.3** times higher in 2022 compared to 2015[2].
SDG 7.2.1



Number of new energy vehicles in China was **23** times higher in 2022 compared to 2015[2].
SDG 7.2.1

Electricity generation from renewable sources transmitted by ultra-high voltage in China was **1.69** times higher in 2021 compared to 2016[2].
SDG 7.2.1

Energy consumption per unit of GDP and number of heat sources from energy-intensive industries in China both decreased by **1/5** compared to 2014[1].
SDG 7.3.1

The cumulative number of countries engaged in energy cooperation with China was **over 90** by the end of 2022[2].
SDG 7.a.1

China's cumulative investment in renewable energy development in developing countries exceeded **USD 100 billion** from 2000 to 2020[1].
SDG 7.a.1

Number of countries (regions) receiving training on solar energy development and utilization from China reached **133** by the end of 2022[2].
SDG 7.a.1

Number of China's international energy cooperation projects reached **437** by the end of 2020[1].
SDG 7.b.1

Notes:
1.Big Earth Data in Support of the Sustainable Development Goals (2022); 2.Big Earth Data in Support of the Sustainable Development Goals (2023).

SDG 7

to 13.1 million in 2022, an increase of nearly 22 times. In 2022, new energy vehicles' sales volume reached 6.887 million, accounting for 61.2% of the global total.

4. In terms of energy efficiency improvement (SDG 7.3), the 2022 report showed that in 2021, China's energy efficiency improved by nearly one-fifth compared to 2014. In 2021, China's energy consumption per unit of GDP and the number of high-energy-consuming industry heat sources both decreased by one-fifth from the peak, contributing to the global improvement of industrial energy efficiency and climate change mitigation efforts.

5. Regarding international energy cooperation (SDG 7.a/SDG 7.b), the 2022 report and the research in this chapter demonstrate that China has established a systematic framework for international energy cooperation, assisting in achieving SDG 7 globally. Through South-South cooperation, the Belt and Road energy ministers' meeting, and other frameworks, China has established government-to-government energy cooperation mechanisms with over 90 countries, regions, and international organizations. China's international energy cooperation projects have enhanced the energy supply capacity of developing countries, and China's total investment in developing renewable energy in other developing countries has reached USD 100 billion. China's overseas industrial parks actively share experiences in green and low-carbon economic development, encouraging local utilization of green and low-carbon energy. Through standard-setting and international training, China helps developing countries increase their energy self-sufficiency capacity. By the end of 2022, 133 countries/regions had participated in training programs on solar energy development and utilization sponsored by China.

7 AFFORDABLE AND CLEAN ENERGY

Thematic Studies

Clean Cooking

Cooking energy has a significant impact on the health of people, and the use of unclean cooking fuels can lead to many diseases. To promote the use of clean cooking energy sources such as natural gas, electricity, liquefied petroleum gas, modern biomass, biogas, and solar energy, SDG 7 specifically includes SDG 7.1.2, which measures the proportion of population with primary reliance on clean fuels. As a populous country, China has over 500 million people living in rural areas. Achieving full coverage of clean cooking energy by 2030 poses a significant challenge. This theme utilizes Big Earth Data technology and combines it with questionnaire surveys to assess the proportion of China's population relying on clean cooking energy and technology, and the key factors influencing the widespread adoption of clean cooking fuels and technology. This information can provide data and references for relevant decision-making.

Proportion of Chinese Population Relying on Clean Cooking Energy and Technologies

SDG 7.1.2: Proportion of population with primary reliance on clean fuels and technology

Using Big Earth Data, including administrative boundary vector maps, GDP, night light remote sensing images, land use data, etc., a combination of spatial analysis, questionnaire surveys, and statistical analysis was conducted. The research followed the main process of "selecting representative provinces/cities, determining survey areas, classifying residential areas, and sampling points," and scientifically analyzed and calculated the proportion of Chinese population relying on clean cooking energy and technologies in different regions, and the usage in different settlements (urban, town, and rural areas). It provided data support for formulating relevant policies, facilitating the popularization of clean cooking energy and technologies in China.

In 2022, the proportion of Chinese population relying on clean cooking energy and technologies was 83.55%. The proportions for urban, town, and rural areas were 100%, 89.38%, and 69.77%, respectively. The number of people not using clean cooking energy and technologies was approximately 150 million. The proportion of people using clean cooking energy and technologies is influenced by various factors such as geographical location, level of economic development, and energy infrastructure. For example, in economically developed regions in eastern China, the proportion of clean energy and technology usage is significantly higher than in western regions (Figure 4-1). High costs of clean energy and inadequate energy infrastructure are key factors limiting the widespread adoption of clean cooking energy and technologies in rural areas.

Gas and electricity are the main sources of clean cooking energy in China, and economic viability and convenience are the primary factors influencing energy choices for both urban and rural residents. The proportion of gas and electricity in household cooking fuels in urban and rural areas is higher than that of other energy sources. In urban areas, approximately 86% of residents use gas and electricity, while in rural areas, this proportion is 71%. With the continuous improvement of renewable energy proportion and electricity infrastructure in China, electricity is expected to become the primary choice for clean cooking energy in rural areas. In urban areas where gas facilities are relatively well-developed, the usage proportion of gas and electricity for cooking is significantly higher than in rural areas. In rural areas without access to natural gas pipelines, liquefied petroleum gas becomes the main clean cooking energy source. When making decisions about energy choices for daily life, both urban and rural residents primarily consider economic viability, accounting for 50% and 53% respectively. Additionally, 30% of urban residents and 20% of rural residents also prioritize the convenience of energy use.

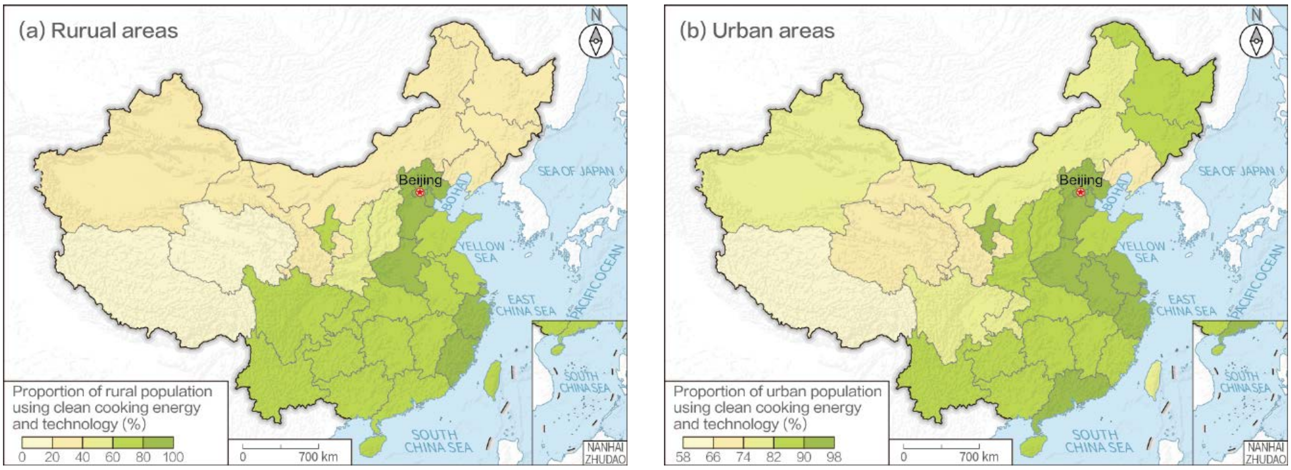


Figure 4-1 Graded color map of the proportion of China's rural and urban population relying on clean cooking energy and technologies in 2022. (a) Rural areas; (b) Urban areas

Renewable Energy

Developing renewable energy is a crucial aspect of addressing the global climate crisis and achieving global energy transition. The proportion of renewable energy in energy consumption is a key indicator for assessing the progress of energy transition under SDG 7. China has put forward the Dual Carbon strategic goals (striving to peak CO_2 emissions by 2030 and achieve carbon neutrality by 2060). Renewable energy has been developed as a priority. As of the end of 2022, China had maintained its position as the world leader in cumulative installed capacity of wind and solar power for 13 and 8 consecutive years, respectively. Based on Big Earth Data, this theme evaluated global wind and solar resources, summarized China's experience in transition to clean energy, and analyzed the role of ultra high voltage in supporting the utilization of renewable energy, providing valuable experience for global energy transition.

Global Wind and Solar Resource

SDG 7.2.1: Renewable energy share in the total final energy consumption

Scientific and accurate quantitative assessment of resources is foundation for large-scale development and utilization of renewable energy. Based on a global high-temporal and spatial resolution wind and solar resource data set and high-resolution geographical information data set, the Geographic Information System spatial analysis method is used to identify the feasible development areas for wind and solar resources by sequentially screening

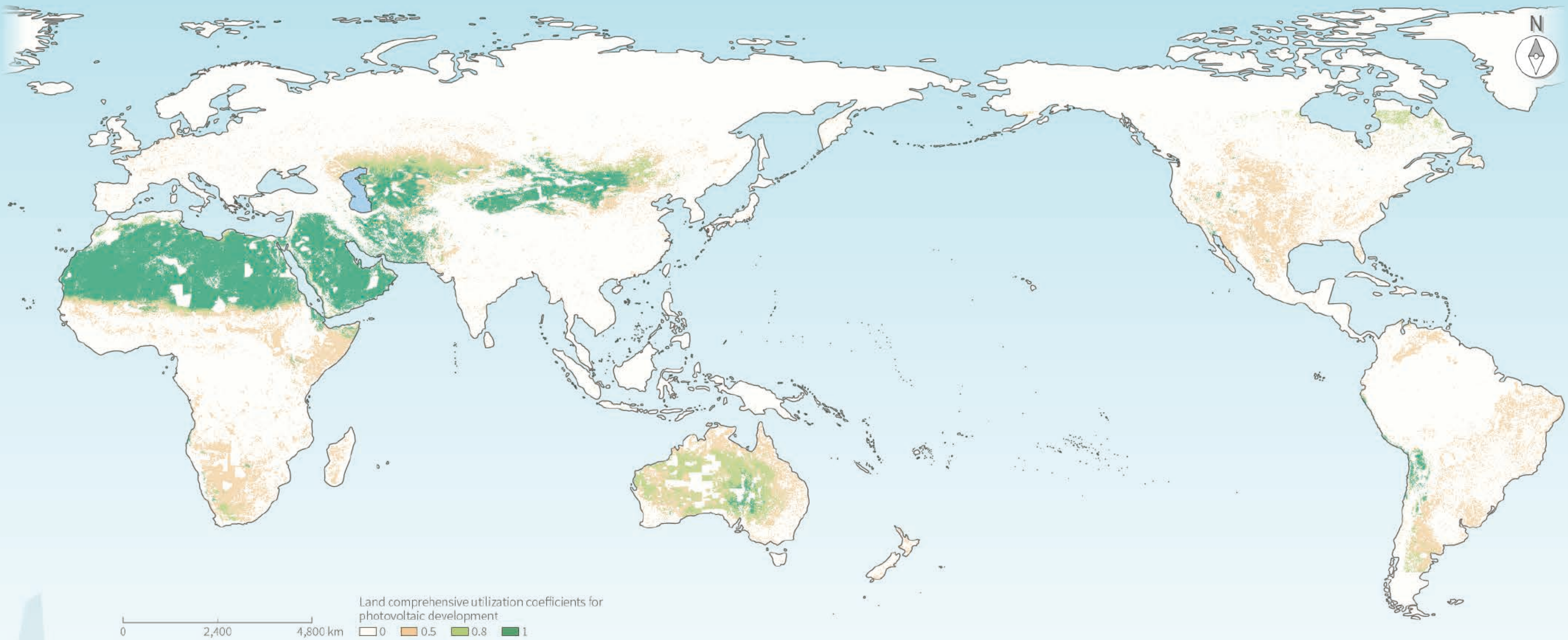


Figure 4-3

Global regions with exploitable onshore solar photovoltaic power and land comprehensive utilization coefficients

Note: the pixel values represent the percentage of land area available for photovoltaic development within each grid

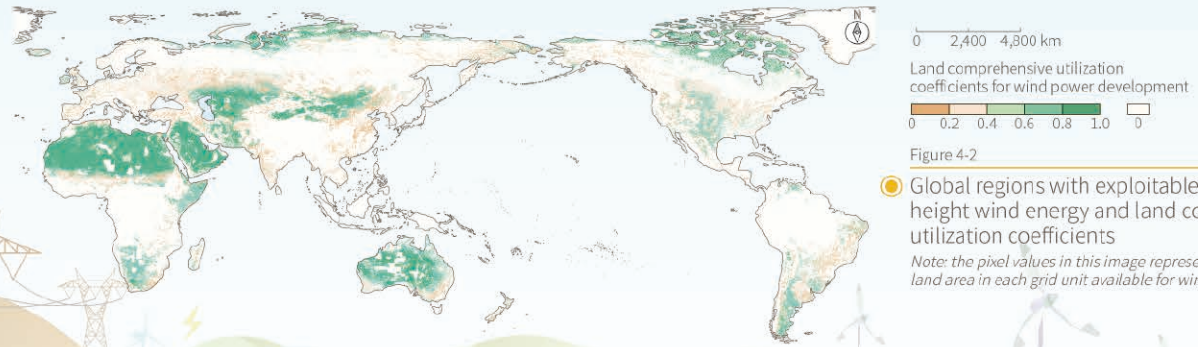


Figure 4-2

Global regions with exploitable land-based 100 m height wind energy and land comprehensive utilization coefficients

Note: the pixel values in this image represent the proportion of land area in each grid unit available for wind power development policy, technical, and economic constraints that affect their development. The research results can support renewable energy planning and efficient utilization of wind and solar resources in countries worldwide. The research results showed that:

Global wind energy resources are abundant, with vast development potential, mainly concentrated in regions suitable for centralized development, such as North Africa, the Middle East, Central Asia, Mongolia, Australia, Northwestern China, and the central United States. Due to atmospheric circulation, terrain, and other factors, global wind energy resources are unevenly distributed, mostly concentrated in coastal areas and narrow passages of open continents (Figure 4-2).

Global solar energy resources are abundant, with tremendous development potential, and suitable regions for centralized development are mainly located in North Africa, the Middle East, Central Asia, Mongolia, Australia, and Northwestern China. Influenced by factors such as solar radiation angles, atmospheric scattering, and sunshine duration, global solar energy resources are mainly concentrated in arid zones between the equator and the Tropics of Cancer and Capricorn that are controlled by the subtropical high-pressure system throughout the year (Figure 4-3).

The 2022 report showed that in the past 10 years, the cost of onshore wind and photovoltaic power generation in China has decreased by 30% and 75%, respectively. Wind and photovoltaic power generation have become new affordable energy sources. The development of wind and solar resources should be fastened to accelerate the process of energy transformation.

China's Clean Energy Transition

SDG 7.2.1: Renewable energy share in the total final energy consumption

Based on the data of China's wind and solar photovoltaic (PV) installed capacity from 2010 to 2022 (National Energy Administration of China, 2011–2023), China's electricity substitution data from 2016 to 2022 (China Electricity Council, 2023), and China's data on new energy vehicles and public charging piles distribution (Ministry of Industry and Information Technology of China, 2022; Ministry of Public Security of China, 2022; National Energy Administration of China, 2011–2023), the analysis using Big Earth Data method examined the changes in the proportion of new energy installed capacity and the contribution of electricity substitution to the overall electrification level in China. This study particularly focused on the development and spatial distribution of new energy vehicles and public charging infrastructure, aiming to inform decisions on global clean energy transition.

Renewable energy has gradually become the main source of electricity in China, with installed capacity surpassing that of coal-fired power for the first time in 2022. As of the end of 2022, China's renewable energy installed capacity reached approximately 1.213 billion kW, accounting for 47.3% of the country's total installed electricity capacity. Among them, wind power accounted for 365 million kW, solar power 393 million kW, biomass power 41 million kW, and hydropower 413 million kW (Figure 4-4). These capacities represent an

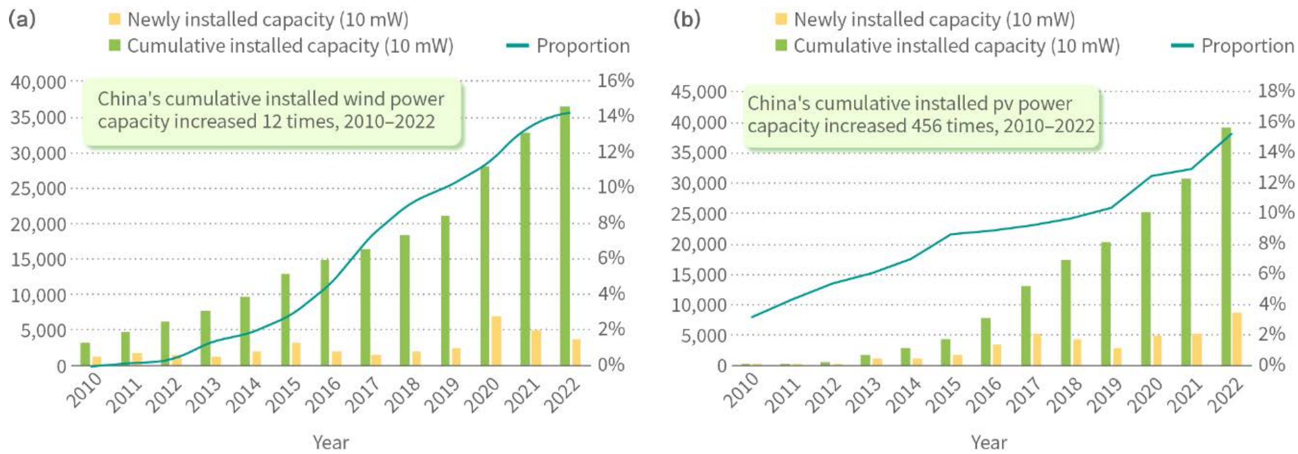


Figure 4-4 China's wind and solar PV installed capacities and proportions, 2010–2022. (a) Cumulative and new wind power installed capacities and proportions, 2010–2022; (b) Cumulative and new PV installed capacities and proportions, 2010–2022

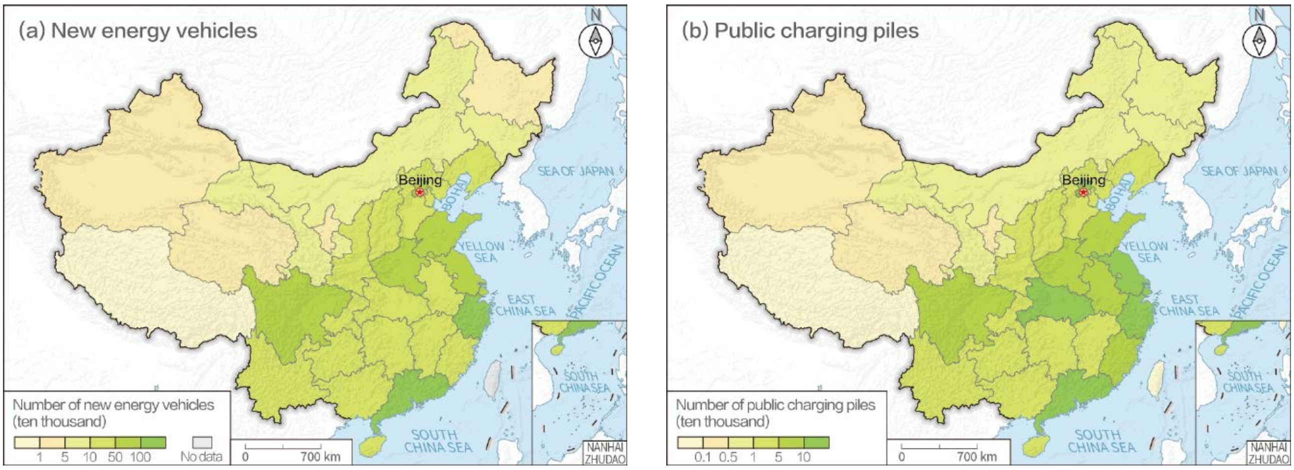


Figure 4-5 Spatial distribution of China's new energy vehicles and public charging stations in 2022. (a) New energy vehicles; (b) Public charging stations

increase of 2.8 times, 9.2 times, 4.0 times, and 1.3 times, respectively, compared to the levels in 2015. In 2022, China's renewable energy generation reached 2.7 trillion kWh, accounting for 31.6% of the total electricity consumption, equivalent to a reduction of approximately 2.26 billion tons of carbon dioxide emissions. In the same year, China's wind and solar power generation reached 1.19 trillion kWh, 5.3 times of 2015. Additionally, China's hydropower generation in 2022 was 1.35 trillion kWh, and biomass power generation reached 182.4 billion kWh, representing 1.2 times and 3.5 times the levels in 2015, respectively.

China has made remarkable progress in promoting electricity substitution, which has facilitated the consumption of clean energy electricity. China has actively promoted electricity substitution in various sectors, including transport, buildings, industry, and agriculture. A series of policies at the national, industrial, and regional levels have been formulated to increase the proportion of electricity in the final energy consumption, which rose from 23.0% in 2016 to 26.9% in 2021 (China Electricity Council, 2023). In the transport sector, China has accelerated its transition to electrification and has become a global leader in the development of new energy vehicles. In 2022, China led the world in sales of new energy vehicles, reaching 6.887 million and accounting for 61.2% of global sales. The number of new energy vehicles in China increased from less than 580,000 in 2015 to 13.1 million in 2022, a growth of nearly 22 times (Ministry of Industry and Information Technology of China, 2022; Ministry of Public Security of China, 2022). The charging infrastructure network in China has also been gradually improved, with the number of charging piles increasing from 66,000 in 2015 to 5.2 million in 2022, a growth of nearly 78 times. Among them, the cumulative number of public charging piles in China reached 1.8 million (Figure 4-5). In 2022, the total electricity consumption for electric vehicles exceeded 40 billion kWh, with a year-on-year growth of over 85% (National Energy Administration of China, 2011–2023), effectively promoting the consumption of clean energy in the electricity sector. For instance, the proportion of clean energy in the charging volume of State Grid Corporation's intelligent vehicle interconnection platform reached 42.6%. In other sectors, China has also achieved remarkable progress in electricity substitution. In the industrial sector, electric boilers, electric kilns, metallurgical electric furnaces, and auxiliary electric power have been vigorously promoted. In the building sector, the use of heat pumps for heating, cooling, and domestic consumption has been expanded. In the agricultural sector, steady progress has been made in the use of electric irrigation pumps and tobacco curing machines, and agricultural machinery electrification.

Ultra-High-Voltage Transmission of Renewable Energy over Long Distance in China

SDG 7.2.1: Renewable energy share in the total final energy consumption

To build the new power system is the key to promoting energy transition. Based on the 2015–2021 *China Renewable Energy Electricity Development Monitoring and Evaluation Report* (National Energy Administration of China, 2016–2022) and the 2015–2021 China Renewable Energy Installed Capacity and Generation Data (China Electricity Council, 2016–2022), an analysis was conducted on the scale, structure, and growth trends of ultra-high-voltage (UHV) transmission of renewable energy, evaluating the supporting role of UHV in the long-distance utilization of renewable energy in China.

As China accelerates the development and utilization of renewable energy, UHV can effectively promote long-distance utilization of renewable energy. In 2022, hydropower in the Southwest and wind and solar power in Northeast, northern part of North China and Northwest accounted for over 57% of China's total renewable energy generation. As two-thirds of China's electricity consumption occur in the eastern regions, renewable energy has to be transmitted over long distance. The power transmission capacity of UHV is 4 to 5 times that of the extra-high-voltage transmission lines, with line losses only about 25%, saving about 60% of land resources. This makes UHV a critical support for the long-distance utilization of renewable energy in China. By the end of 2022, China had completed 35 UHV transmission projects, with a total length of constructed and under-construction transmission lines exceeding 50,000 km and a transmission capacity over 10,000 kW, delivering a cumulative electricity amount of over 2.5 trillion kWh.

UHV has facilitated the utilization of renewable energy, with the proportion of renewable energy electricity exceeding 50% of all transmitted. The amount of UHV-transmitted electricity in China continues to grow. In 2021, the annual electricity transmitted through 17 operational direct current UHV lines was 488.7 billion kWh, 2.45 times that of 2016. Among them, the renewable energy electricity transmitted through UHV in 2021 was 287.1 billion kWh, 1.69 times that of 2016. The transmitted renewable energy through UHV is showing an increasing trend, accounting for 58.7% of the total. In terms of renewable energy types, wind and solar power transmitted through UHV in 2021 were approximately 97 billion kWh, 7.9 times that of 2016, while hydroelectric power reached 190.1 billion kWh, equivalent to 28% of hydropower generated in Sichuan and Yunnan.

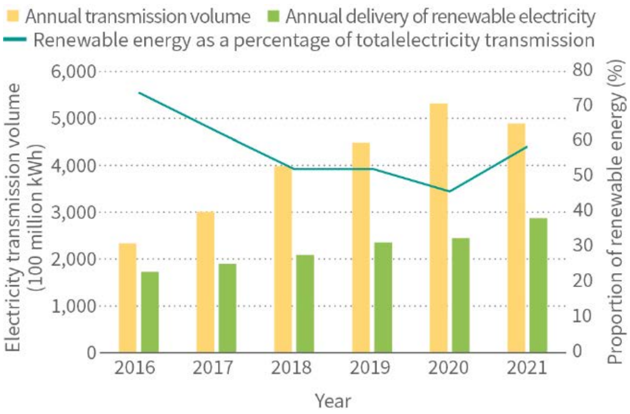


Figure 4-6 China's UHV transmission of renewable energy electricity

Note: 2021 data refers to direct current UHV data.

International Energy Cooperation

Developing countries generally face energy shortages. In the context of global energy transition, the development of new, green and renewable energy is considered a key solution for developing countries to achieve energy self-sufficiency and energy transition. However, due to the lack of funds and technology, and the backwardness of energy infrastructure, developing countries face greater uncertainties in achieving energy self-sufficiency. To promote the development of renewable energy in developing countries, two major targets, SDG 7.a and SDG 7.b, are devoted to it. China has actively responded to the UN 2030 Agenda by engaging in global energy cooperation, within frameworks such as South-South cooperation, the Belt and Road Initiative, and the Global Development Initiative, becoming an important source of funding and technology for renewable energy development in developing countries. This theme summarizes China's international energy cooperation from aspects of policy frameworks, energy project collaboration, green and low-carbon energy utilization and transition, and energy technology cooperation, aiming to provide reference for global energy cooperation.

China's International Cooperation on Clean Energy

SDG 7.a: By 2030, enhance international cooperation to facilitate access to clean energy research and technology, including renewable energy, energy efficiency and advanced and cleaner fossil-fuel technology, and promote investment in energy infrastructure and clean energy technology

SDG 7.b: By 2030, expand infrastructure and upgrade technology for supplying modern and sustainable energy services for all in developing countries, in particular least developed countries, small island developing States, and landlocked developing countries, in accordance with their respective programmes of support

Based on the export statistics data of solar energy products from China Customs from 2015 to 2022 and self-developed data sets on China's international energy cooperation projects, this study used spatial statistical analysis methods to analyze the effectiveness of China's international energy cooperation from aspects of policy frameworks, energy project collaboration, green and low-carbon energy utilization and transition, and energy technology cooperation.

China has established a comprehensive and multi-level framework for international energy cooperation. International cooperation and assistance are crucial for developing countries to achieve energy accessibility and transition. China has established multi-tiered energy cooperation platforms and mechanisms through South-South cooperation, the Belt and Road Energy Ministers' Meeting, China-European Union High-Level Dialogue on Environment and Climate, China-Africa Cooperation Forum, and other frameworks. These platforms and mechanisms partner China with the Arab League, the African Union, ASEAN, Central and Eastern Europe, and APEC in energy cooperation. China also has government-level energy cooperation mechanisms with more than 90 countries, regions, and international organizations. These efforts support global energy diversification and promote green development.

China actively engages in global clean energy cooperation through investment, construction, aid, product supply, and capacity cooperation, assisting developing countries in addressing energy shortages and promoting global energy transition. China's international energy cooperation projects have reached 437, of which the number and installed capacity of renewable energy power stations account for 51.26% and 41.35%, respectively, significantly improving the energy supply levels of developing countries. From 2000 to 2020, the China Development Bank and the China Export-Import Bank provided overseas energy financing totaling USD 234.6 billion, with direct investment in renewable energy accounting for 42.75%. By the end of 2022, China's photovoltaic companies' overseas factories in Southeast Asia have a capacity exceeding 40 GW. From 2015 to 2022, China supplied over 520 GW of photovoltaic components to the global market (Figure 4-7). China also provides assistance in constructing small hydropower plants, off-grid solar systems, and other energy projects, helping unelectrified areas and communities in remote regions. For instance, from 2015 to 2022, China donated 53,494 solar photovoltaic products to Africa (Figure 4-8).

Chinese overseas industrial parks actively share experience of green and low-carbon development, promoting local energy utilization that meets the goal of green and low-carbon development. These overseas industrial parks

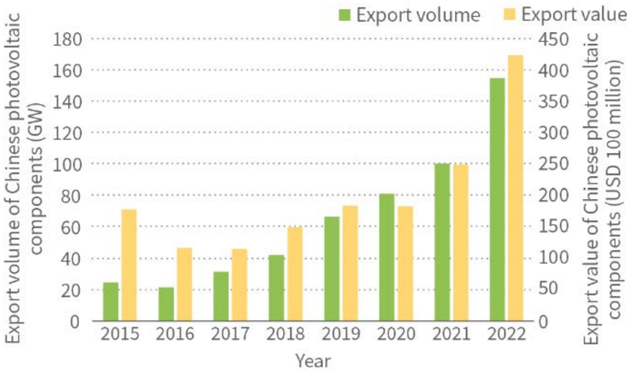


Figure 4-7 Export volume and export value of Chinese photovoltaic components, 2015–2022

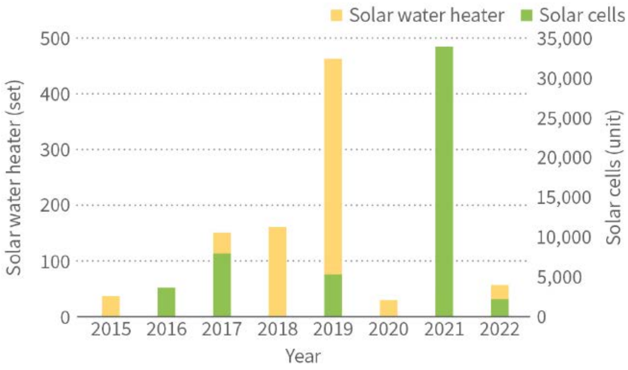


Figure 4-8 Quantity of solar energy products donated by China to Africa, 2015–2022

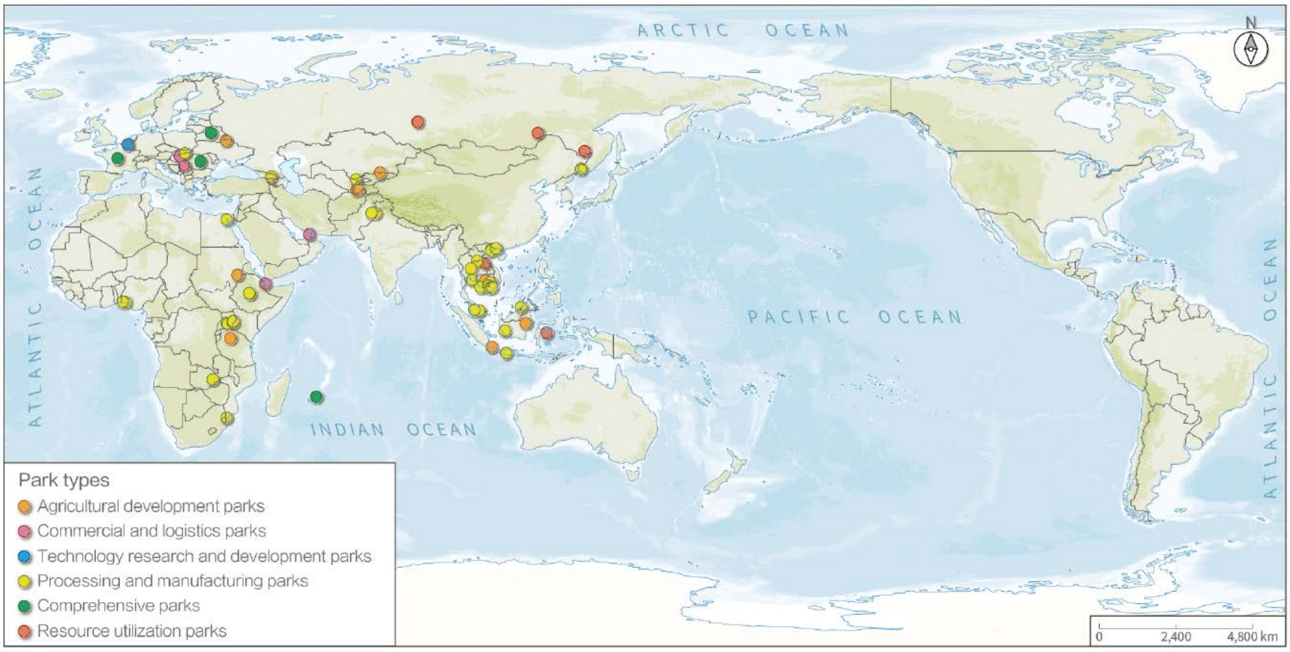


Figure 4-9 Geographical distribution of 60 Chinese overseas industrial parks

consistently draw upon and learn from successful practices in ecological conservation and circular economy from both domestic and international parks (Figure 4-9). Their level of green and low-carbon development has constantly improved, with the Green Development Index increasing from 61.5 points in 2013 to 70.5 points in 2019, up by 14.7%. Their energy intensity and carbon emissions intensity have decreased year by year, with the average energy intensity at 1.21 tons of standard coal per USD 10,000, which is about 50% to 60% lower than the local average level and they have basically reached the advanced level of developed countries (Song Jing *et al*., 2022). At these overseas industrial parks, the average green coverage is around 30%, and the completion rates of centralized sewage treatment facilities and infrastructure are both around 60%, meeting China's low-carbon industrial park pilot index value. Their green and low-carbon performance levels are generally higher than the local average, and most of them have become benchmarks and models for promoting green and low-carbon development in their host countries, driving continuous improvement in local industrial standards.

China's international energy cooperation aims to empower developing countries and enhance their energy self-reliance. Through assistance in planning and standard-setting and personnel training, China's international energy cooperation enhances the capabilities of developing countries in clean energy utilization, technology research and development, project construction and operation. For instance, in the field of planning and standard-setting, China, together with the United Nations Industrial Development Organization (UNIDO), signed a memorandum of understanding on cooperation to jointly promote international standards for small hydropower development and co-authored the Technical Guidelines for the Development of Small Hydropower Plants. The memorandum of understanding was included in the outcome list of the 2nd Belt and Road Forum for International Cooperation held in April 2019. In May 2022, the Technical Committee 339 Small Hydropower Plants of International Organization for Standardization (ISO/TC339) was approved for the establishment, with its secretariat based in China. China has also provided energy consulting and planning services to countries such as Ghana, Tanzania, and Cote d'Ivoire. In terms of training, China has sponsored training for more than 2,000 solar energy technicians from 133 developing countries, and through the Green Silk Road Ambassador Program provided training to over 3,000 talents from more than 120 countries participating in the Belt and Road Initiative.

7 AFFORDABLE AND CLEAN ENERGY

Recommendations and Outlook

This chapter focuses on topics such as clean cooking, renewable energy, and international energy cooperation, and evaluates China's population ratio relying on clean cooking energy and technology, and global wind and solar resources, and summarizes China's experiences in clean energy transition and international energy cooperation. Based on this and considering the work done in 2022 and 2023, a midterm progress assessment of the global/China SDG 7 indicators was conducted. The research findings indicate that wind and solar renewable energy have become reliable and affordable energy sources and will play a key role in future energy development. However, inadequate infrastructure and insufficient funding, especially for supporting renewable energy projects in developing countries, are the main reasons behind the slow progress on SDG 7.

Based on the research conducted in this chapter, we propose the following recommendations to accelerate progress on SDG 7 globally:

1. Enhancing energy infrastructure is crucial to achieving energy access. Infrastructure and energy prices are critical factors limiting the widespread adoption of clean cooking energy. In 2022, the proportion of Chinese rural population using clean cooking energy was only 69.77%. To achieve global access to clean energy, infrastructure development, such as rural electric network and pipeline networks, must be enhanced. To promote the realization of SDG 7.1, we recommend that energy infrastructure coverage be added as a new indicator, including the proportion of electrified built-up areas.

2. Developing renewable energy sources like wind and solar is essential for achieving global energy transition. Global renewable resources, such as wind and solar, have tremendous potential and can play a crucial role in achieving global energy transition and responding to climate change. However, the current Nationally Determined Contributions (NDCs) for electricity targets globally only account for 40% of the renewable energy power needed to meet the global climate goals by 2030. To promote the development of wind, solar, and other renewable energy sources, China's 14th Five-Year Plan for Renewable Energy Development proposes that the non-hydro renewable energy electricity consumption should reach around 18% by 2025. Therefore, we recommend that the proportion of non-hydro renewable energy installed capacity be added as a new indicator under SDG 7.2.

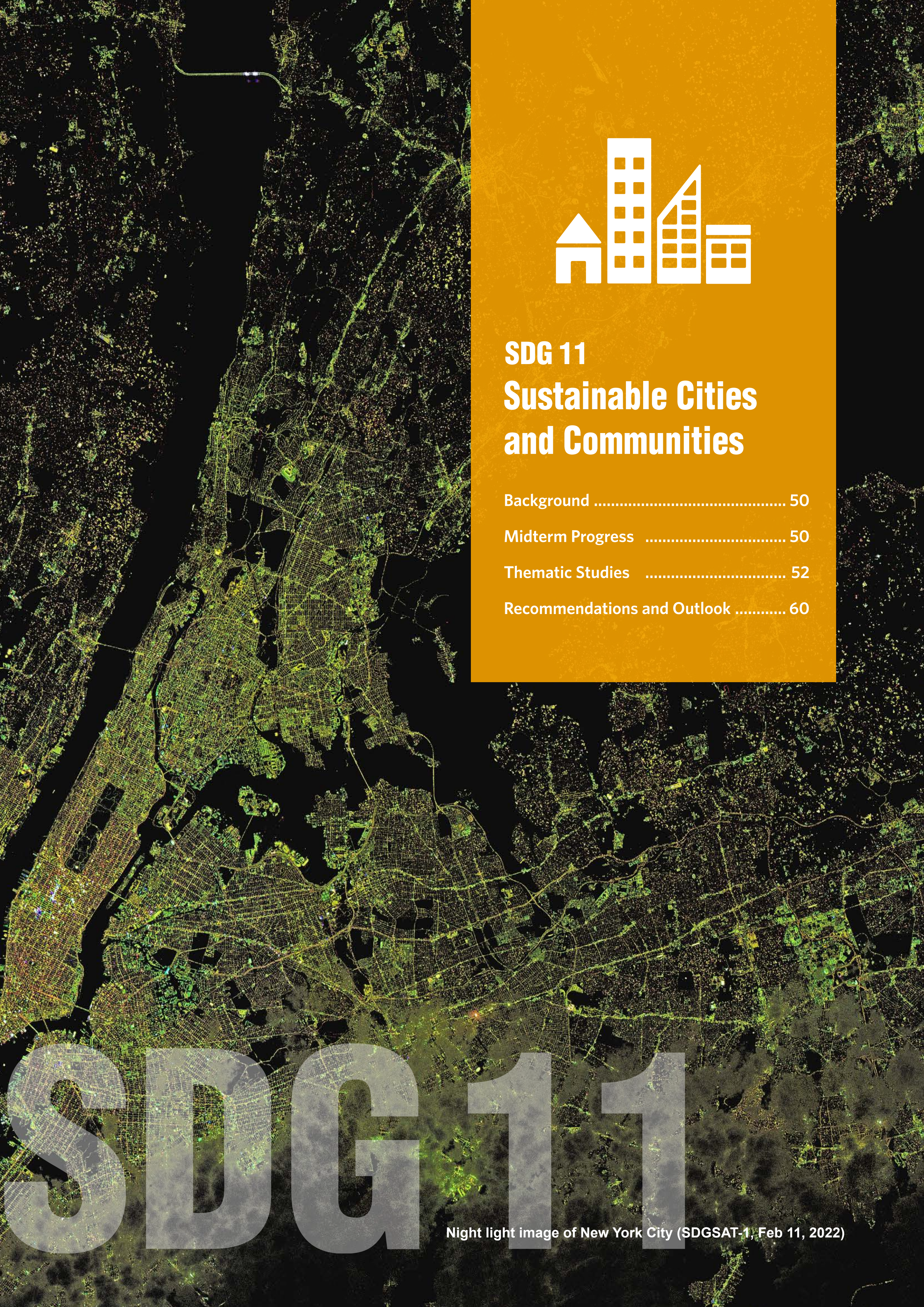
3. International energy cooperation is crucial for developing countries to achieve SDG 7. For instance, 35% of the installed capacity of power plants in Nepal relies on international investment. However, foreign investment flowing into developing countries has shown a significant downward trend, with this funding even being one-third less since 2020 than the average of the previous decade (IEA *et al.*, 2023). Developed countries should actively implement the annual USD 100 billion climate compensation to support modern energy access and energy transition in developing countries.

Big Earth Data has already played an important role in achieving global energy access and transition. To support the realization of SDG 7 globally and China's Double Carbon goals, we will further explore the potential of Big Earth Data technology in wind and solar resource development, providing scientific data and decision-making support for global energy access and transition.

SDG 7

SDG 11

Sustainable Cities and Communities



Night light image of New York City (SDGSAT-1, Feb 11, 2022)

Background

Achieving sustainable cities and communities (SDG 11) is crucial in addressing climate change, promoting economic growth, and reducing poverty and pollution. By 2030, it is projected that 60% of the global population will reside in urban areas (Chen *et al*., 2022), and this proportion is expected to reach nearly 70% by 2050 (Sun *et al*., 2020). However, despite contributing 75% of the global GDP, urban areas also generate 75% of waste and carbon emissions worldwide. Rapid urbanization has led to challenges such as housing shortages, traffic congestion, air pollution, waste management issues, and inadequate infrastructure and services. Unplanned urban expansion makes cities more susceptible to the impacts of climate change and natural disasters. Currently, over 4 billion urban residents still face serious problems such as air pollution, inadequate infrastructure, and uncontrolled urban development.

SDG 11 aims to build inclusive, safe, resilient, and sustainable cities and human settlements, comprising seven technical targets and three policy targets. Among the 17 SDGs included in the United Nations 2030 Agenda, SDG 11 is interconnected with multiple other SDGs, and around one-third of the 230 plus indicators can be measured at the city level. However, many indicators lack data support despite having evaluation methods, presenting a significant challenge in monitoring and assessing progress toward the targets and indicators. Big Earth Data technologies, such as satellite remote sensing and GIS, can regularly obtain global data, uncover drivers of progress toward SDG 11, and serve as important data sources and analysis tools for global sustainable development research.

Over the past four years, progress on SDG 11 has been monitored and assessed at both global and Chinese scales, providing strong support and guidance for urban sustainable development. This year's report will focus on targets, such as urban public transport (SDG 11.2), heritage preservation (SDG 11.4), and urban air pollution (SDG 11.6). The report will summarize the midterm progress of SDG 11, and on this basis, assess the proportion of the global population with convenient access to public transport, supplement data on natural and mixed World Heritage boundaries, analyze the changes in average concentration of atmospheric particulate matter worldwide, and establish an evaluation system for urban construction management and living environments. This chapter will focus on the midterm progress assessment of SDG 11 at the global/Chinese scale, providing a scientific foundation and experiential reference to reveal the current status of global/Chinese implementation of SDG 11 and to support the achievement of SDG 11.

Midterm Progress

Based on the reports from 2019 to 2022 and the findings of this chapter, an assessment was done of the midterm progress on targets related to safe housing, urban public transport, urbanization, heritage preservation, urban disaster management, urban air pollution, open public spaces, and urban-rural regional development. The research indicates that from 2015 to 2022, the global population with convenient access to public transport in major cities increased by 3.38%. The concentration of atmospheric fine particulate matter in typical regions showed a decreasing trend globally. The quality of data related to natural and mixed World Heritage boundaries has significantly improved. China has made noticeable progress in the construction of hardware infrastructure in its cities. Since 2015, all SDG 11 indicators in China have shown significant advancements. Specific progress is as follows:

1. In safe housing (SDG 11.1), the 2022 report revealed that from 2015 to 2020, the permanent population living in original slums in major Chinese cities decreased from 22.025 million to 15.242 million, a decrease of 30.8%. The transformation of slums in China's major cities has yielded remarkable results, improving the living environment for residents.

2. In urban public transport (SDG 11.2), the research of this report shows that by 2020, the global weighted average of the population with convenient access to public transport in major cities exceeded 60%, but remained relatively uneven. Nearly all communities in major Chinese cities witnessed an increase in transport convenience, and significant expansion

SDG 11

of the coverage of public transport.

3. In urbanization (SDG 11.3), the 2022 report indicated that global urbanization overall moved towards balanced development. The global urban land use efficiency index decreased from 1.65 in 2000–2005 to 1.31 in 2015–2020, showing more balanced development of urban expansion and population growth.

4. In heritage preservation (SDG 11.4), the 2022 report showed a positive trend in global heritage preservation. From 2010 to 2020, the land cover change related to human activities within 90% of the global heritage sites and their buffer zones was less than 5%; within 90% of the protected areas of global heritage sites, land cover change was less than 1% from 2015 to 2020.

5. In urban disaster management (SDG 11.5), the 2022 report indicated a significant decrease in the number of people affected by extreme disasters and the death toll globally. However, there has been a considerable increase in the direct economic loss indicator. In China, both monitoring indicators, the number of deaths and directly affected people (SDG 11.5.1) and direct economic losses (SDG 11.5.2), show a clear downward trend.

6. In urban air pollution (SDG 11.6), this report demonstrates that the overall global $PM_{2.5}$ concentration showed a decreasing trend from 2015 to 2022. From 2015 to 2022, China's average annual $PM_{2.5}$ concentration decreased annually, with more apparent declines observed in city clusters such as Beijing-Tianjin-Hebei, Chengdu-Chongqing, the Yangtze River Delta, and the Pearl River Delta, reflecting

SDG 11 Sustainable Cities and Communities: Global/China Midterm Progress

China's population living in slums reduced by **6.783 million** from 2015 to 2020[1].

SDG 11.1.1

Global urban land use efficiency index decreased from **1.65** in 2000–2005 to **1.31** in 2015–2020[1].

SDG 11.3.1

Global change of heritage site protection coverage was less than **1%** from 2015 to 2020[1].

SDG 11.4.1

Global average $PM_{2.5}$ concentration decreased by **4.4μg/m³** from 2015 to 2020[2].

SDG 11.6.2

China contributed **28%** of the global area of significantly greening urban regions in 2021[1].

SDG 11.7

Weighted average of population with access to convenient public transport exceeded over **60%** globally in 2020[2].

SDG 11.2.1

Human activities caused less than **5%** of land cover changes in World Heritage sites from 2015 to 2020[1].

SDG 11.4.1

The number of affected persons per 100,000 population, the number of deaths and missing persons per 100,000 population, and direct economic losses in relation to GDP in China decreased by **58.2%**, **54.7%** and **50.8%** respectively in 2021, compared with annual average values from 2010 to 2020[1].

SDG 11.5.1 SDG 11.5.2

Population-weighted annual average $PM_{2.5}$ concentration decreased by **19.6ug/m³** in China from 2015 to 2022[2].

SDG 11.6.2

Notes:

1.Big Earth Data in Support of the Sustainable Development Goals (2022); 2.Big Earth Data in Support of the Sustainable Development Goals (2023).

SDG 11

China's significant achievements in comprehensive air pollution control in recent years.

7. In open public spaces in cities (SDG 11.7), the 2022 report showed that since 2010, urban green spaces in built-up areas have significantly increased, leading to notable ecological greening in cities. China contributes 28% of the globally significant greening areas in urban regions, despite only accounting for 19% of global urban built-up areas. Around 310 million people worldwide have directly benefited from significant urban greening, with China's population accounting for approximately 47% of the global beneficiaries.

8. In urban-rural regional development (SDG 11.a), this report reveals that from 2000 to 2020, the economic aggregate of China's 11 urban-rural integration development pilot zones has significantly increased. Among them, the development level and speed of mixed towns with predominantly rural characters have been the highest, indicating that the economic aggregate and economic spatial growth rate of towns related to rural areas have far exceeded those related cities. The processes of urbanization and rural revitalization have reduced the economic gap between urban and rural areas.

9. In the comprehensive assessment of SDG 11 at the city level in China, the 2021 report showed that the Composite Index score of SDG 11 increased from 64 points in 2015 to 73 points in 2020, indicating favorable sustainable performance among various municipal administrative regions. Among them, 300 municipal administrative regions experienced an increase in the Composite Index for SDG 11.

Thematic Studies

Urban Public Transport

Public transport is a critical form of urban transport and a major choice for city residents for mobility. An efficient and reliable public transport system can reduce urban congestion and air pollution, while promoting economic growth and social progress (Saif *et al.*, 2019). Therefore, achieving sustainable urban public transport is also a crucial area within the SDGs. To accomplish this goal, a people-centric approach is essential, focusing on accessibility and quality of public transport, adopting sustainable technologies and strategies, promoting the development of urban public transport, and enhancing the mobility experience for citizens. This way, people can have convenient, low-carbon, and high-quality transport options in cities.

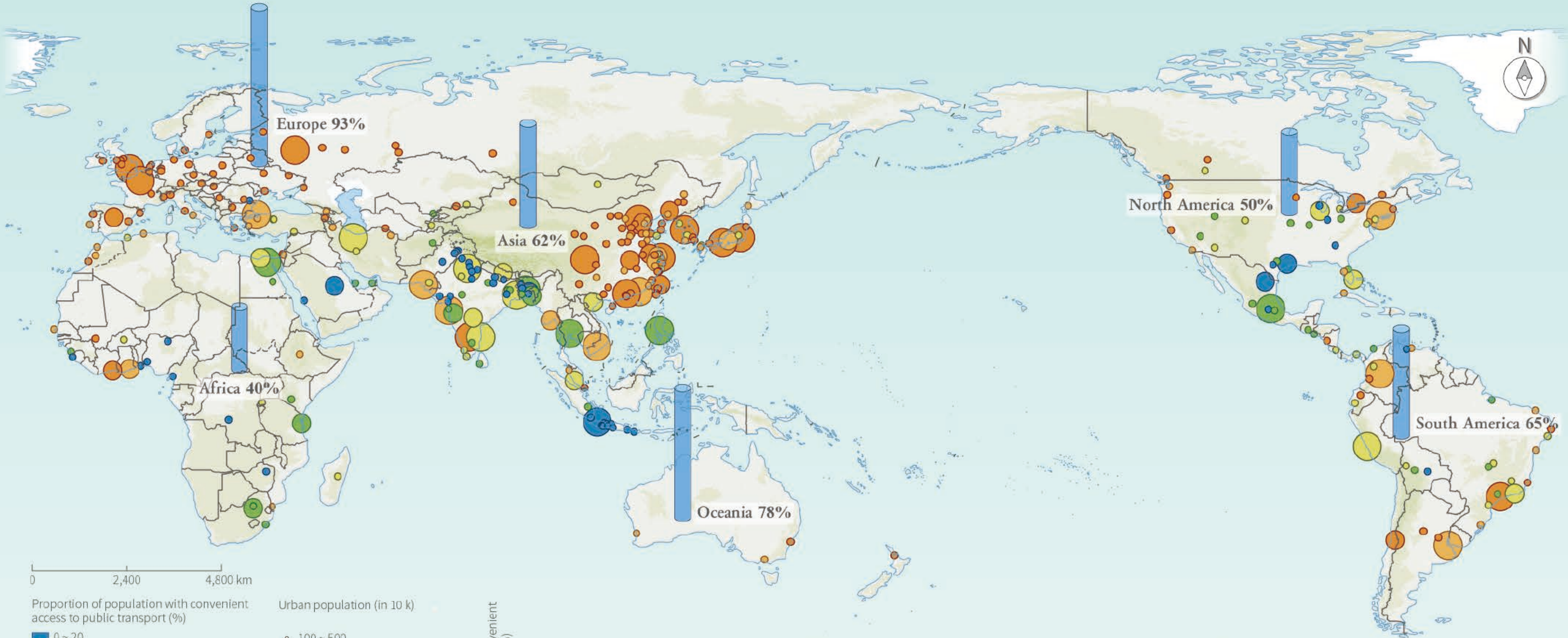
Global Proportion and Variation of Population with Access to Convenient Public Transport in Major Cities

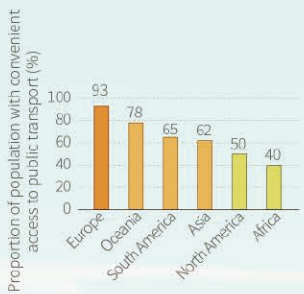
SDG 11.2.1: Proportion of population that has convenient access to public transport, by sex, age and persons with disabilities

Based on data sets on global major cities' public transport and population density, spatial analysis methods such as overlay analysis and spatial statistics were applied to analyze the proportion and variation of the population with access to convenient public transport in 330 major cities globally.

In 2020, the population-weighted average proportion of people with access to convenient public transport in major cities worldwide exceeded 60%. European and East Asian cities had relatively high values (> 80%), while values were relatively low in Africa and South Asia (< 20%) (Figure 5-1). The population-weighted average proportion of European cities with convenient access to public transport was about 2.3 times higher than that of African cities.

The proportion of population with convenient access to public transport is uneven globally. In 2020, the population-weighted average in major cities worldwide increased by 3.38% compared to 2015; about one seventh of cities showed an increase of over 10%, mainly outside Europe, China experienced significant improvement in the proportion of population with convenient access to public transport. Cities with initially low accessibility to public transport experienced significant improvements in 2015. The





In 2020, the weighted average of population with convenient access to public transport exceeded **60%** in the world's major cities

Values for European and East Asian cities (**> 80%**)

Africa and South Asia have relatively low values (**< 20%**)

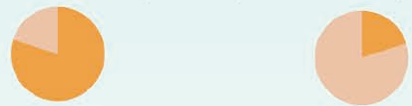
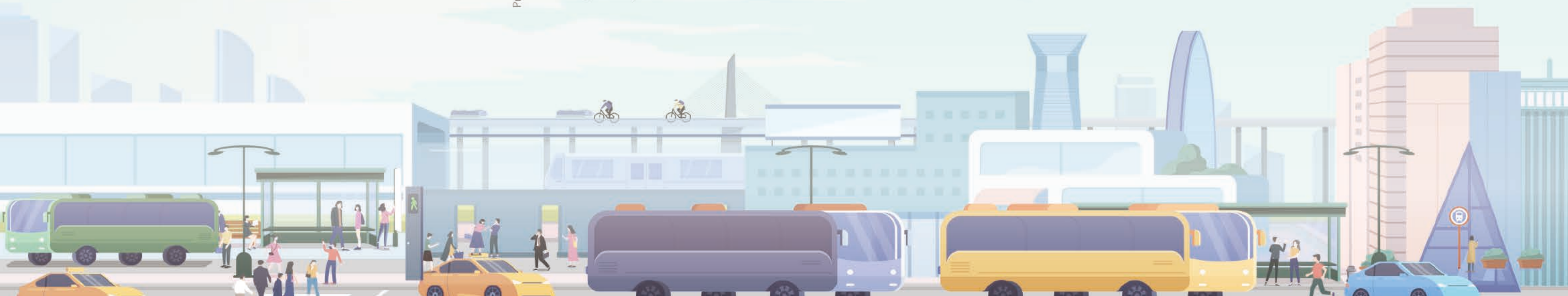


Figure 5-1

Percentage of the world's population with convenient access to public transport in 330 major cities in 2020



Gini coefficient of Public Convenient Accessibility to Public Transport (PCAPT) for 330 major global cities was 0.59 in 2020, remaining relatively stable compared to 2015 (if this value is considered relatively balanced when below 0.4). Cities with higher PCAPT values were primarily located in economically developed regions, with significantly higher values in Europe and East Asia compared to the global average. Southeast Asia, the Middle East, and Africa had PCAPT values below the global average. In the Americas, cities with economic prosperity and political stability had higher PCAPT values, while others had relatively low values. Looking at changes in PCAPT values, areas with higher values in 2020 showed relatively small changes, but the Middle East experienced more significant changes compared to other regions. In Africa, regions with higher PCAPT values in 2020 saw substantial growth, while regions with lower values showed less noticeable changes between 2015 and 2020, indicating rapid development in areas with higher PCAPT values in recent years.

Heritage Conservation

Heritage conservation aims to protect, inherit, and sustainably utilize cultural and natural heritage worldwide, which represents the rich diversity of human civilization and the natural evolution of the Earth. Heritage conservation not only preserves cultural traditions but also creates opportunities for tourism, education, and economic development. Using big data-based sustainable methods is crucial for heritage preservation, including ensuring the integrity of heritage conservation data, supporting sustainable tourism, heritage education, and community engagement with big data, all of which contribute to ensuring the sustainability of heritage conservation.

Natural and Mixed World Heritage Sites Open Boundary Data Quality Improvement

SDG 11.4: Strengthen efforts to protect and safeguard the world's cultural and natural heritage

Boundaries are an important basis for the integrity conservation and management of World Heritage sites. The existing publicly available heritage boundary information has quality problems such as completeness, consistency and accuracy due to the inconsistency in the format and accuracy of boundary data submitted during the early nomination process of some heritage sites, and the multiple sources of data from relevant international agencies and organizations. Based on the existing publicly available data resources, this case uses big data technology, with the support of international institutions and organizations such as the International Union for Conservation of Nature (IUCN) and the International Centre on Space Technologies for Natural and Cultural Heritage (HIST) under the auspices of UNESCO, to carry out a quality verification and updating of the existing boundary data of the natural and mixed World Heritage, and proposes measures to improve the management of the data.

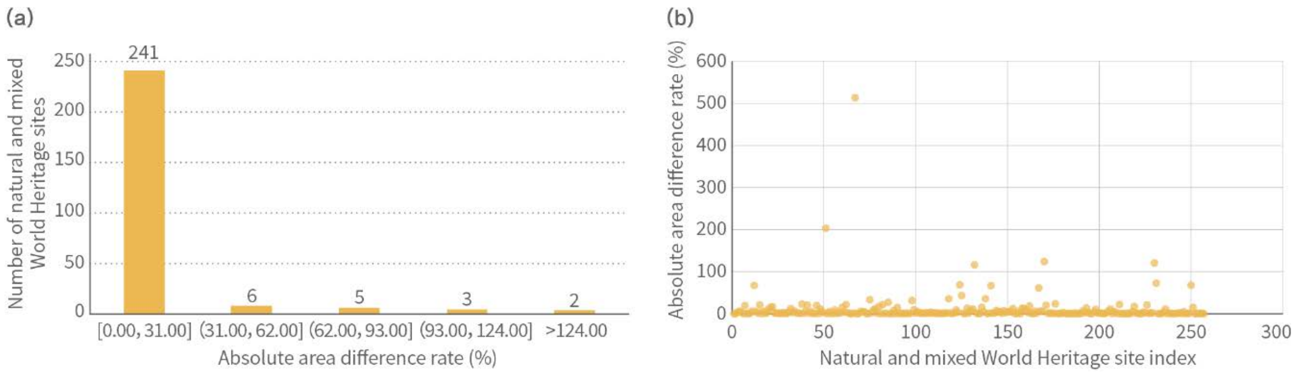


Figure 5-2 Absolute area difference rate between the latest area on the official website and boundary vector database graphical GIS area. (a) Number of natural and mixed World Heritage sites in each interval of the absolute area difference rate; (b) Distribution of values of the absolute area difference rate for each natural and mixed World Heritage site

The case study analyzes the absolute area difference rate between the boundary data of the World Database on Protected Areas (WDPA) and the archival data obtained from the website of UNESCO World Heritage Centre (WHC), and provides a reference for the improvement and updating of heritage boundary data.

The WDPA, established in 1981, is the most comprehensive global database on terrestrial and marine protected areas, which includes vector and attribute data on the boundaries of natural and mixed World Heritage sites. Based on the data of 250 natural and mixed World Heritage sites extracted from WDPA (as of April 2023), by calculating the absolute area difference rate between the latest reported area in the archival data on the WHC website and the area of vector boundaries in the WDPA database, it is concluded that the absolute area difference rate is within 10% in 80.5% of the natural and mixed World Heritage sites, and the absolute area difference rate is greater than 10% in 50 natural and mixed World Heritage sites, and the maximum difference rate reaches 513.44%, as shown in Figure 5-2.

Based on the information extraction method of Natural Language Processing (NLP), the case extracts and collates the boundary information of natural and mixed World Heritage sites from the WHC website and related English websites. The case also analyses the content and spatial references of the map files of natural and mixed World Heritage sites in the WHC website. We found that 129 (50%) of the 257 natural and mixed World Heritage Sites have complete map elements information, 126 have incomplete map elements, and two sites lack boundary maps. Therefore, there is an urgent need to improve and update the maps and boundary information in the WHC website. Currently the boundary vector data of natural and mixed World Heritage sites based on the WDPA database has been updated with the cooperation of HIST and IUCN, and in the future, with the improvement of the information on the WHC website, the quality of the boundary vector database can be improved accordingly.

Based on the boundary information extraction method of NLP, this case verifies the completeness and consistency of the boundary information of the natural and mixed World Heritage Sites, sorts out the common and individual problems of the boundary data, and produces the boundary vector data of the natural and mixed World Heritage Sites based on the vector data of the WDPA and the map update of the WHC website (Figure 5-3). The case provides the latest data support for the conservation, management and research of natural and mixed World Heritage Sites, and provides ideas and references for UNESCO to improve and update the heritage data, so as to respond to the heritage conservation strategy of UNESCO and the SDGs, and support the global conservation and sustainable development of World Heritage.

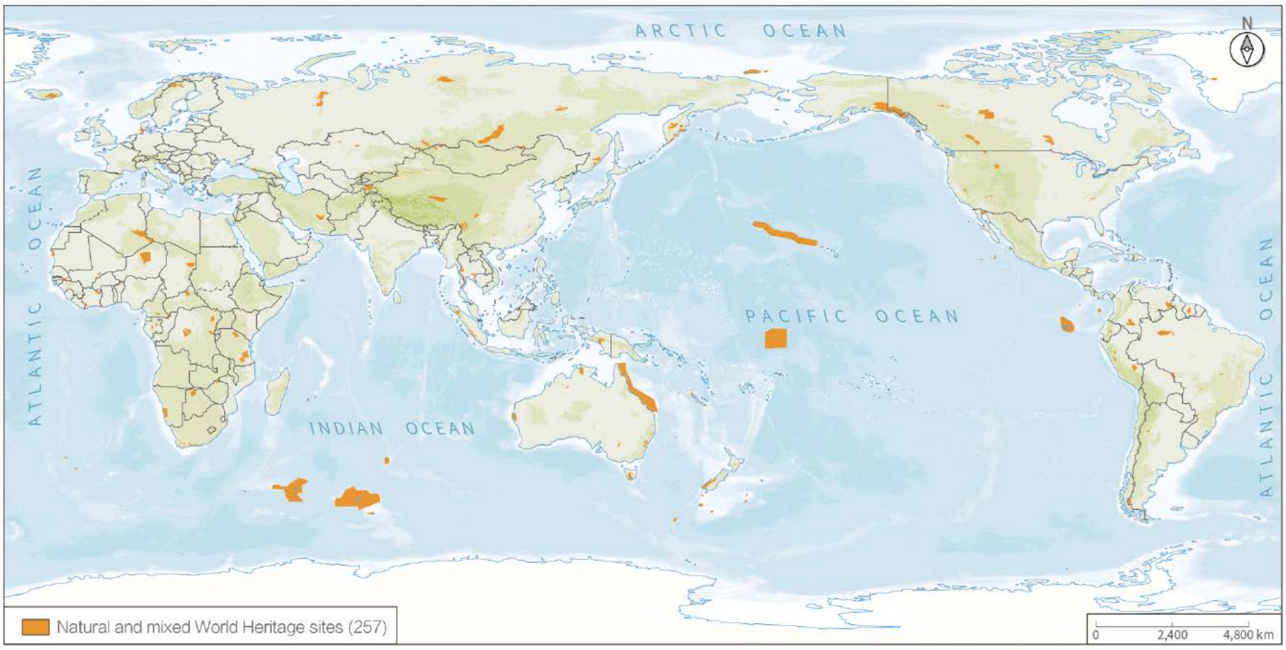


Figure 5-3 Natural and mixed World Heritage Sites vector data updated based on WDPA vector data and maps on WHC website

Urban Environment

Global Temporal and Spatial Trends of Atmospheric Particulate Matter

SDG 11.6.2: Annual mean levels of fine particulate matter (e.g. $PM_{2.5}$ and PM_{10}) in cities (population weighted)

By integrating data from global atmospheric environmental monitoring, a data set for atmospheric particulate matter and auxiliary data from 2015 to 2022 was established. GIS analysis methods were used to depict the spatial distribution of various air pollutants and determine the global interannual variations in air pollutant concentrations.

From 2015 to 2022, the average concentration of $PM_{2.5}$ was 20 μg/m^3, with 92% of urban sites exceeding the annual average concentration standard of 10 μg/m^3 set by the World Health Organization's (WHO) in 2005. High $PM_{2.5}$ concentrations were mainly found in densely populated areas of Asia, the Middle East, and Western Europe. In Asia, India and China had higher $PM_{2.5}$ concentrations, with only a few cities meeting WHO's air quality standards. In the Middle East, due to its arid and semi-arid climate, dust contributed significantly to total particulate matter, resulting in moderate concentrations. $PM_{2.5}$ concentrations in Europe were relatively low, with slightly higher levels in Eastern Europe compared to Western Europe. North America had the lowest levels of particulate matter concentrations among all continents, with higher concentrations observed mainly in major cities on the eastern and western coasts. Due to limited monitoring stations, available data for South America and Africa could not reflect the overall situation on those continents, but they did indicate mild to moderate pollution levels in the relevant cities.

The spatial distribution of NO_2 was similar to that of $PM_{2.5}$, while O_3 showed some differences from NO_2 and $PM_{2.5}$. NO_2 was mostly found in heavily populated cities, but with lower concentrations in remote areas. O_3 remained high in Asia, mainly due to the continuous increase in volatile organic compound emissions in recent years. However, India, one of the regions with severe particulate matter pollution, had relatively low O_3 concentrations, mainly attributable to the uptake of oxidants by particulate matter of high concentrations in the atmosphere.

From 2015 to 2020, $PM_{2.5}$ concentrations showed an overall declining trend, with the global average concentration decreasing from 21.6 μg/m^3 to 17.2 μg/m^3. After 2020, there was a slight upward trend, reaching 19.4 μg/m^3 in 2022 (Figure 5-4). The interannual variation trend of NO_2 was similar to that of $PM_{2.5}$, with the global average concentration decreasing from 12.7 μg/m^3 in 2015 to 9.9 μg/m^3 in 2020 and then reaching a peak of 13.1 μg/m^3 in 2022. The interannual variation trend of O_3 showed slight differences from $PM_{2.5}$ and NO_2. Except for a low value in 2015, the average concentration remained around 23 μg/m^3 from 2016 to 2018 and then decreased significantly over the next four years, stabilizing at around 21 μg/m^3. The main pollutants in the atmosphere reached their lowest values during the study period in 2020 and 2021.

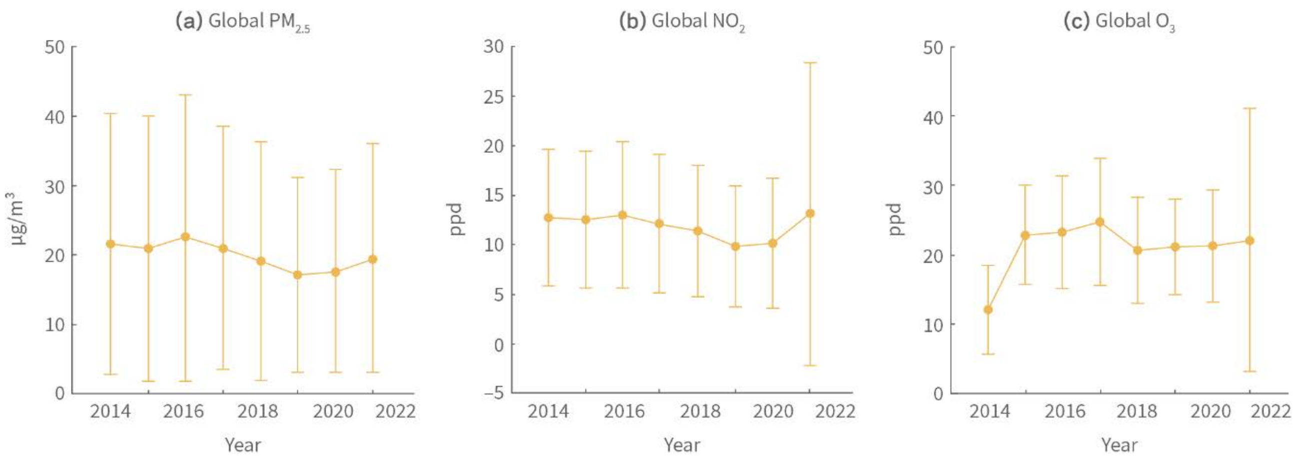


Figure 5-4 Interannual variation trends in global concentrations of $PM_{2.5}$, NO_2, and O_3, 2015–2022

Long-Term High-Resolution $PM_{2.5}$ Retrieval and Trends in China

SDG 11.6.2: Annual mean levels of fine particulate matter (e.g. $PM_{2.5}$ and PM_{10}) in cities (population weighted)

Based on the data from China's air quality ground monitoring station network, a comprehensive data set was created, combining multiple sources of data related to $PM_{2.5}$ spatiotemporal variations, including visibility, meteorological elements, satellite aerosol and NO_2 products, and socio-economic factors (Bai *et al.*, 2022; Yang *et al.*, 2021; Wang *et al.*, 2023; Wei *et al.*, 2023). By utilizing the random forest algorithm, a predictive model was developed to retrieve the $PM_{2.5}$ daily gridded data set covering the entire spatial extent from 2015 to 2022. Then the trends in $PM_{2.5}$ concentrations based on population weighting were also assessed.

From 2015 to 2022, both national and key regional $PM_{2.5}$ concentrations in China showed a decreasing trend (Figure 5-5). The key urban clusters, including the Beijing-Tianjin-Hebei and surrounding areas, the Yangtze River Delta, the Fenwei Plain, Chengdu-Chongqing, the middle reaches of the Yangtze River, and the Pearl River Delta, experienced more prominent declining trends in $PM_{2.5}$ concentrations. This reflects the significant achievements of China's comprehensive actions in air pollution control and prevention. However, in the northwestern regions of China, such as Xinjiang, where the population density is low and natural geographical conditions such as vast deserts and Gobi exert negative impact, $PM_{2.5}$ concentrations remain fairly high.

From 2015 to 2022, the exposure risk to $PM_{2.5}$ for Chinese residents gradually decreasd, particularly in densely

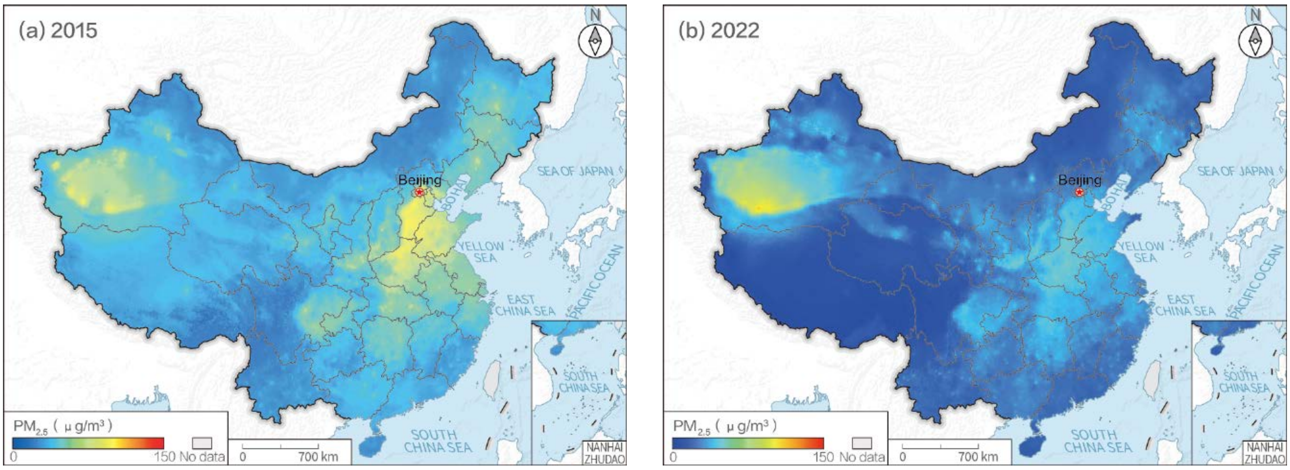


Figure 5-5 Spatial distribution of annual average $PM_{2.5}$ concentrations in China during 2015–2022

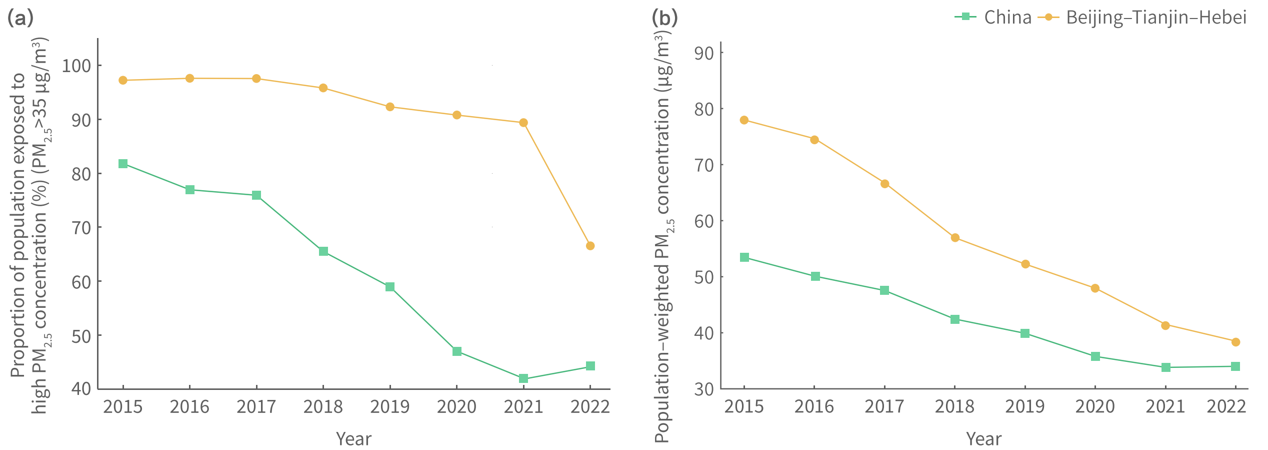


Figure 5-6 The risk of $PM_{2.5}$ exposure to Chinese residents during 2015–2022. (a) the trend of the proportion of the population exposed to high $PM_{2.5}$ concentration (>35 μg/m^3) ; (b) annual average population-weighted $PM_{2.5}$ concentration in China and Beijing-Tianjin-Hebei region

populated urban clusters where the risk had significantly decreased. The changes in annual average $PM_{2.5}$ concentrations, weighted by population, are noticeable, with a national decline rate of 3.1 μg/(m^3•a), representing a reduction of 36.5%. In the Beijing-Tianjin-Hebei region, the decline rate and reduction reached 6.0 μg/(m^3•a) and 50.7%, respectively. The gap in population-weighted $PM_{2.5}$ concentrations between the Beijing-Tianjin-Hebei region and the entire country has been gradually narrowing (Figure 5-6). Additionally, by calculating the proportion of the population exposed to high $PM_{2.5}$ concentrations (annual average > 35 μg/m^3), the results show that by 2022, the national proportion decreased to 44.2%, while the proportion in the Beijing-Tianjin-Hebei region decreased to 66.5%. These findings reflect the substantial reduction in $PM_{2.5}$ pollution levels in China in recent years, achieved through comprehensive air pollution control actions, leading to significant improvements in the health of Chinese residents and benefiting a wider population.

SDG 11 Comprehensive Assessment

The process of localizing SDG 11 in global cities still faces many challenges. At the international level, all cities encounter issues related to data collection, processing, and management (Fox *et al*., 2022). These challenges are manifested in several aspects: Firstly, due to differences among countries and regions, and in data availability, SDG indicators may not be applicable to specific local circumstances (Greene *et al*., 2017). Secondly, local governments lack the institutions and capabilities for data collection. For instance, many city-level governments lack the data monitoring capacity possessed by national-level governments, further exacerbating the problem of mismatched data scales (Barnett *et al*., 2016). Lastly, the flow of resources, people and information that sustains city development crosses the boundaries of local political jurisdictions, making the measurement of urban sustainability progress a uniquely complex challenge (Da Cruz *et al*., 2019; Fox *et al*., 2019).

Urban Assessment and Sustainable Development Goals

SDG 11: Make cities and human settlements inclusive, safe, resilient and sustainable

To address the deficiencies in indicator data and Comprehensive Index results for the localization of SDG 11, and the lack of clarity in assessment methods at the city level, this case aims to supplement the relevant data from two perspectives:

1. Based on the “check-ups” for pilot cities, the SDG 11 indicator system is localized, and data from pilot cities are collected, using the latest data collection methods.

2. By drawing on existing United Nations research, a Comprehensive Index is developed by fitting multiple indices, providing Chinese urban managers with quantitative analysis results for comprehensive decision-making. It also serves as a tool for monitoring the process of achieving the SDGs by 2030. Data, collected from 59 pilot cities that had “check-ups” in 2022, went through

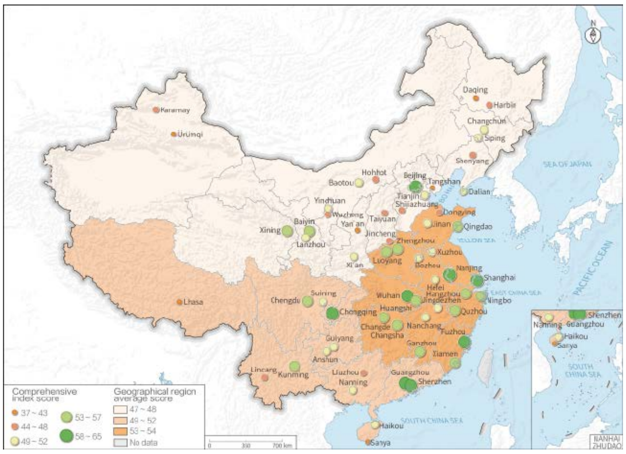


Figure 5-7 Spatial distribution of SDG 11 localization comprehensive index results in 2022

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[1] The term "diamond structure" is used in China's urban research field to refer to a diamond-shaped distribution formed by four economic and social development growth poles of national importance: the Pearl River Delta, the Yangtze River Delta, the Beijing-Tianjin-Hebei region, and the Chengdu-Chongqing region.

spatial analysis and generated results of the localized Comprehensive Index for SDG 11, as shown in Figure 5-7.

The spatial pattern of the urban Comprehensive Index exhibits a high similarity to the "diamond structure"[1] of urban economic and social development. Core cities in well-developed urban clusters, such as the Pearl River Delta, Yangtze River Delta, Beijing-Tianjin-Hebei, Chengdu-Chongqing, the middle reaches of the Yangtze River, and the western coast of the Taiwan Strait, have higher levels of development. At the city level, Fuzhou, Shanghai, Guangzhou, Shenzhen, and Nanjing have the highest scores, reflecting their efforts and achievements in building inclusive, safe, resilient, and sustainable cities and human settlements. At the regional level, Central and Eastern China have the highest average scores, followed by South and Southwest China, while North China, Northwest China, and Northeast China have the lowest scores, indicating distinct differences between the eastern and western, and northern and southern regions.

The seven major geographical regions, rated by the average scores of the Comprehensive Index, from high to low, are as follows: Central China, East China, South China, Southwest China, North China, Northwest China, and Northeast China. Overall, cities in the central and eastern regions perform better than those in the western and northeastern regions (Figure 5-8). Specifically, as shown in Figure 5-9, all regions have achieved relatively high levels in ensuring housing and basic services (SDG 11.1), building transport systems (SDG 11.2), reducing negative environmental impacts (SDG 11.6), and providing public spaces (SDG 11.7). Recent assessments have consistently demonstrated significant progress in the hardware infrastructure development of Chinese cities.

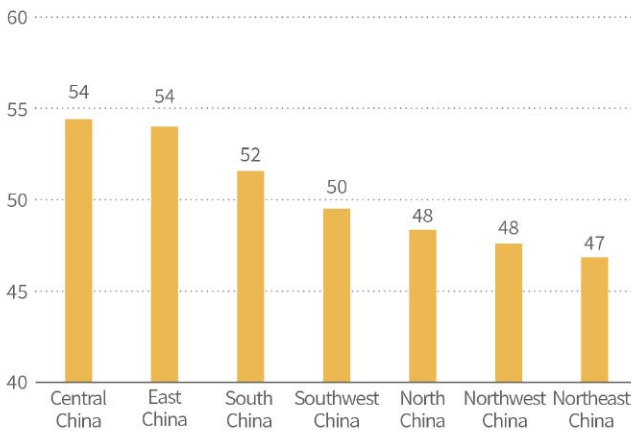


Figure 5-8 Bar chart of the average scores of SDG 11 localization comprehensive index by geographical regions in 2022

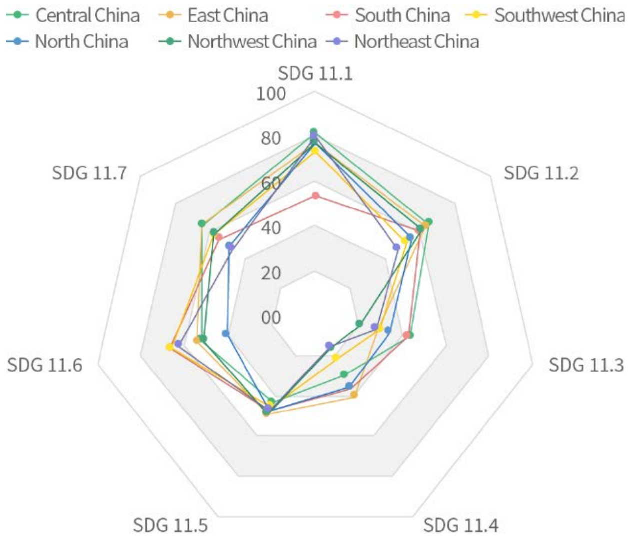


Figure 5-9 Radar chart of average sub-index scores for SDG 11 localization by geographical regions in 2022

11 SUSTAINABLE CITIES AND COMMUNITIES

Recommendations and Outlook

In this chapter, we focused on the theme of sustainable cities and communities, conducting research on midterm progress in safe housing, urban public transport, urbanization, heritage conservation, urban disasters and responses, urban air pollution, open public spaces in cities, and urban-rural regional development. Based on these studies and the outcomes of the past five years' case studies, we summarized the global, regional, and Chinese progress towards SDG 11. The research findings reveal that the proportion of people with convenient access to urban public transport has increased in major global cities, global heritage conservation is showing positive development, and the sources of typical urban atmospheric particulate matter are influenced by multiple factors. China is very close to realizing the indicator on the proportion of people with convenient access to urban public transport, and the risk of exposure to $PM_{2.5}$ for Chinese residents is gradually decreasing. The localized Composite Index for SDG 11 shows differentiated characteristics, and Chinese cities have made significant progress in infrastructure construction. These research results will provide vital support for fine-grained analysis of progress in different regions and for scientific decision-making on sustainable cities and communities.

Based on the research in this chapter, we propose the following recommendations:

1. To increase the proportion of people with convenient access to urban public transport and address the issue of uneven transport convenience globally, efforts should be made to strengthen the construction and improvement of urban public transport systems and promote the integration of public transport planning with urban planning.

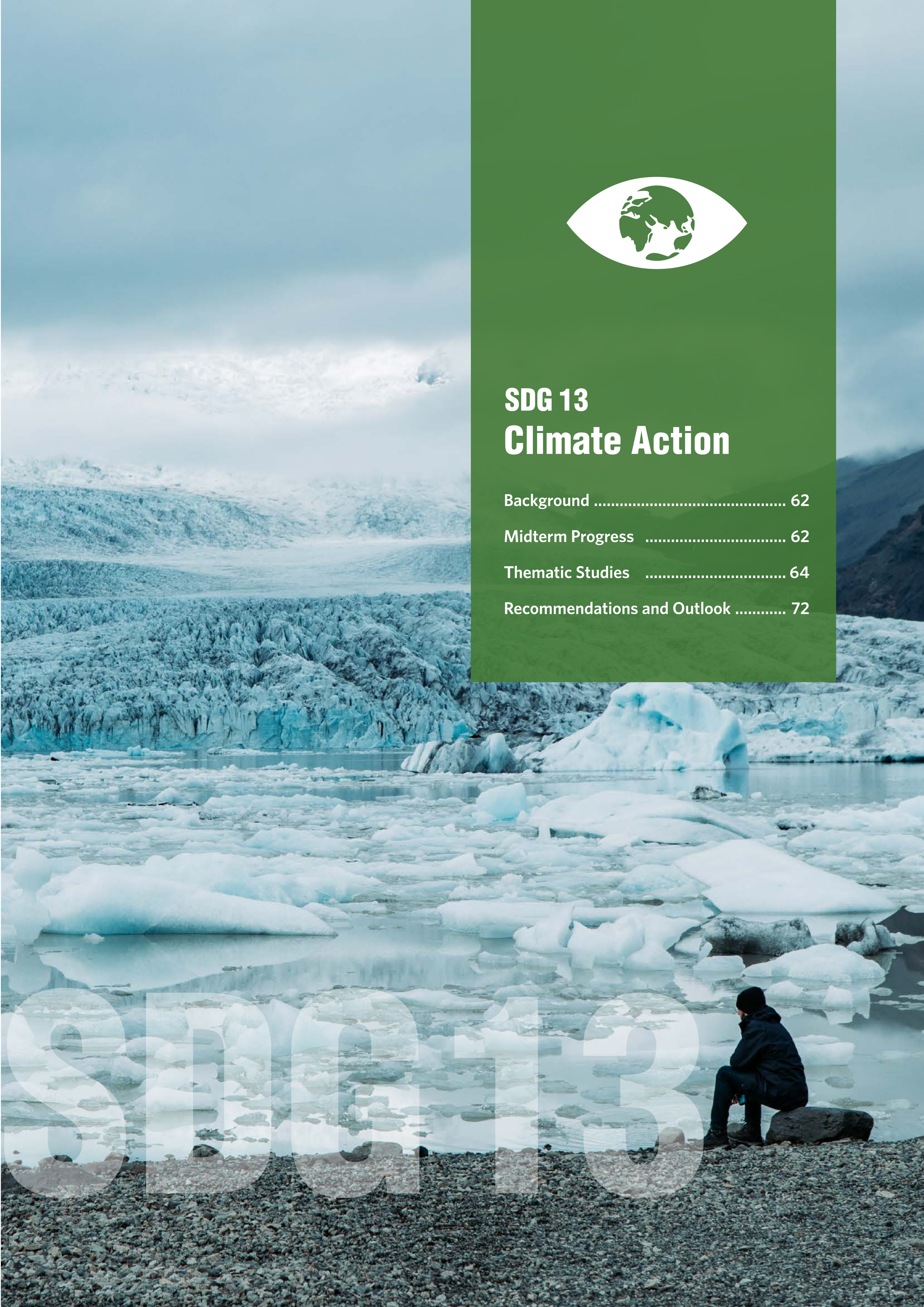
2. Data completeness and accuracy are crucial for heritage conservation work. Timely updates of the World Database on Protected Areas and improvement of information on the UNESCO World Heritage Centre website are necessary in order to have accurate data on natural and mixed World Heritage boundaries.

3. In comprehensive efforts to improve global air quality and conduct attribution studies, attention should be paid not only to areas with existing well-established monitoring networks and complete data, but also to regions with inaccurate or incomplete data, such as desert areas like the Gobi Desert.

4. We should enhance the research on localized assessment of the sustainability of Chinese cities, improving monitoring of changes in urban sustainable development and optimization of capabilities. Particular attention should be given to the sustainable development of cities in western and northeastern regions, especially in areas related to housing and public services, environmental pollution control, and disaster resilience.

5. A localized SDG 11 indicator system should be established, one that is adaptable to the national context and conditions of each country, promoting the collection and integration of multi-source data to facilitate quantitative assessments of development goals.

Looking forward, with the continuous development of Big Earth Data technology, we can monitor and evaluate urban development trends more comprehensively and accurately. This will allow us to make more effective use of information on population flow and resource utilization, to provide rich data for sustainable cities and communities, inform policy on new indicator development, and offer scientific basis for government planning and decision-making.



SDG 13
Climate Action

13 CLIMATE ACTION

Background

Global greenhouse gas concentrations continue to rise, leading to record-breaking global average temperatures. This trend results in an increase in extreme weather events, and an acceleration of glacier and ice cap melting, causing rising sea levels and posing a threat to biodiversity (WMO, 2023). The *Global Risks Report 2023* indicates that the three greatest risks facing humanity in the next decade are the inability to mitigate climate change, the inability to adapt to climate change, and extreme natural disasters, all of which are closely related to climate change. Climate change is already seriously threatening human survival and development (WEF, 2023). The United Nations *Sustainable Development Goals Report 2022* points out that the world is on the edge of a climate catastrophe, and the window for avoiding it is closing. Global greenhouse gas emissions are still increasing, and all countries need to take immediate action to shift from the tipping point of a climate disaster to a turning point towards a sustainable future (UN, 2022). After announcing carbon peak and carbon neutrality goals in 2020, China released in 2022 the *National Climate Change Adaptation Strategy 2035*, promoting enhanced adaptive capacity and proactive responses to climate change.

SDG 13 Climate Action aims to take urgent action to combat climate change and its impacts. However, it is currently the most data-deficient among all 17 SDGs, with only about 20% of countries having relevant data (UN, 2022), and data with spatial and temporal information is even scarcer. Therefore, there is an urgent global need for data that can reflect overall progress towards SDG indicators while providing spatial details and temporal trends to inform decisions on disaster response and climate change mitigation.

The reports from 2019 to 2022 focused on five indicators: disaster losses (SDG 13.1.1), national disaster risk reduction strategies (SDG 13.1.2), proportion of local governments with disaster risk reduction strategies (SDG 13.1.3), greenhouse gas emissions (SDG 13.2.2), and climate change education (SDG 13.3.1). They provided indicator calculation methods, spatial-temporal data products, and scientific decision support at both the Chinese and global scales.

This year's report for the first time includes China's climate change response strategy (SDG 13.2.1/SDG 13.b.1) and provides new developments in flood disaster impacts, global greenhouse gas budgets, and public awareness of climate change. Additionally, this chapter systematically summarizes the achievements of Big Earth Data in the past five years, evaluating the midterm progress on seven indicators in SDG 13 at both the Chinese and global levels, providing scientific data support for formulating disaster prevention and reduction and greenhouse gas emission reduction strategies.

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Midterm Progress

Based on the reports from 2019 to 2022 and the content of this chapter, the progress of the seven SDG 13 indicators at the global and Chinese scales was evaluated. The results show that globally disaster losses (SDG 13.1.1) have significantly decreased, while greenhouse gas emissions (SDG 13.2.2) continue to rise. In China, five indicators (SDG 13.1.1 disaster losses, SDG 13.1.2 national disaster risk reduction strategies, SDG 13.1.3 proportion of local governments with disaster risk reduction strategies, SDG 13.2.1/SDG 13.b.1 climate change response strategies) have already been achieved ahead of schedule, while the other two indicators face certain challenges (SDG 13.3.1 climate change education, SDG 13.2.2 greenhouse gas emissions). The specific midterm progress is as follows:

1. In disaster risk reduction, the reports from 2021 and 2022 showed that China has established a comprehensive national disaster risk reduction strategy (SDG 13.1.2) based on the Sendai Framework for Disaster Risk Reduction (referred to as the "Sendai Framework"), and the proportion of local governments with disaster risk reduction strategies (SDG 13.1.3) has reached 100%. Since the implementation of the Sendai Framework, the number of people affected, the number of deaths and missing persons attributed to disasters per 100,000 people (SDG 13.1.1), and the average

annual direct economic losses as a percentage of GDP decreased by 57.7%, 64.8%, and 48.3% respectively from 2016 to 2021, compared to the levels of 2010 to 2015, basically achieving these indicators. During the same period, the global average number of people affected and deaths from extreme weather and climate events decreased by 42.2% and 78.0% respectively, compared to 2000 to 2015, but economic losses showed an increasing trend.

2. In response to climate change, this report's research shows that China has clearly defined carbon peak and carbon neutrality goals after 2020, and the strategic system for addressing climate change (SDG 13.2.1/ SDG 13.b.1) is gradually becoming clear. However, the control of greenhouse gas emissions (SDG 13.2.2) still faces significant pressure. Global greenhouse gas emissions briefly declined in 2020 but rebounded in 2021, approaching the levels before the COVID-19 pandemic, and the impact of the pandemic on carbon emissions has largely disappeared.

3. In climate change education, the reports from 2022 and this report's research show that climate change education and communication in China (SDG 13.3.1) are still stages, and the proposal of carbon peak and carbon neutrality goals has significantly improved public awareness of climate change issues.

SDG 13 Climate Action: Global/China Midterm Progress

Global disaster-affected populations and death toll decreased by **42.2%** and **78.0%**, respectively, in 2016–2021 from 2000–2015[1].

SDG 13.1.1

China's disaster-affected populations and death toll per 100,000 people decreased by **57.7%** and **64.8%**, respectively, in 2016–2021 from 2000–2015[1].

SDG 13.1.1

By 2022, China has established a **complete** national disaster reduction policy system based on the Sendai Framework[1].

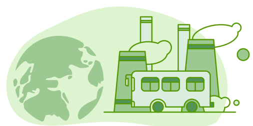
SDG 13.1.2

100% of China's provincial governments have established disaster reduction policy systems during 2015–2022[1].

SDG 13.1.3

By 2022, China has established **clear** national climate change adaptation plans and long-term strategies[2].

SDG 13.2.1 SDG 13.b.1



Global greenhouse gas emissions continued to **rise** from 2019 to 2022[2].

SDG 13.2.2

China's greenhouse gas emissions also continued to rise from 2019 to 2022 but **at a slower pace**[1,2,3].

SDG 13.2.2

By 2022, China's climate change education and communication (SDG 13.3.1) are still at the **early stages**[1,2].

SDG 13.3.1

Notes:

1.Big Earth Data in Support of the Sustainable Development Goals (2022); 2.Big Earth Data in Support of the Sustainable Development Goals (2023); 3.Big Earth Data in Support of the Sustainable Development Goals (2021).

13 CLIMATE ACTION

Thematic Studies

Reducing the Impact of Climate-related Disasters

Flood disasters account for the highest proportion, up to 40%, of all economic losses caused by natural disasters globally. China is one of the countries most prone to frequent and severe flood disasters, with approximately two-thirds of its territory susceptible to various types and degrees of flooding. Remote sensing technology is an effective means of monitoring flood disasters (DeVries *et al*., 2020; Zhu *et al*., 2022).

Analysis of the Impact of Flood Disasters and Defense Effectiveness in China

SDG 13.1: Strengthen resilience and adaptive capacity to climate-related hazards and natural disasters in all countries

Using multi-source remote sensing and survey data from GF-3, Sentinel-1, etc., the region growing method was employed to extract the maximum monthly water body coverage, and then subtracted from the normal water body range to obtain the monthly flood coverage, area, and spatiotemporal changes in China. This study conducted a spatial distribution investigation of flood submergence in China in the two years of 2020 and 2021. Additionally, by combining data from the *China Flood and Drought Disaster Prevention Bulletin* and the *China Statistical Yearbook*, the changes in indicators such as the number of deaths, missing persons, affected population, crop affected areas, and direct economic losses due to flooding from 2010 to 2021 were analyzed. The study also assessed the flood control and disaster reduction benefits of China's flood defense measures, in line with the evaluation of SDG 13.1.1.

In 2020, China experienced the most severe flooding since 1998. Utilizing multi-temporal remote sensing data from different sources, the extent of water bodies before and after the disaster was extracted to visualize the spatial distribution of flood submergence (Figure 6-1). The worst

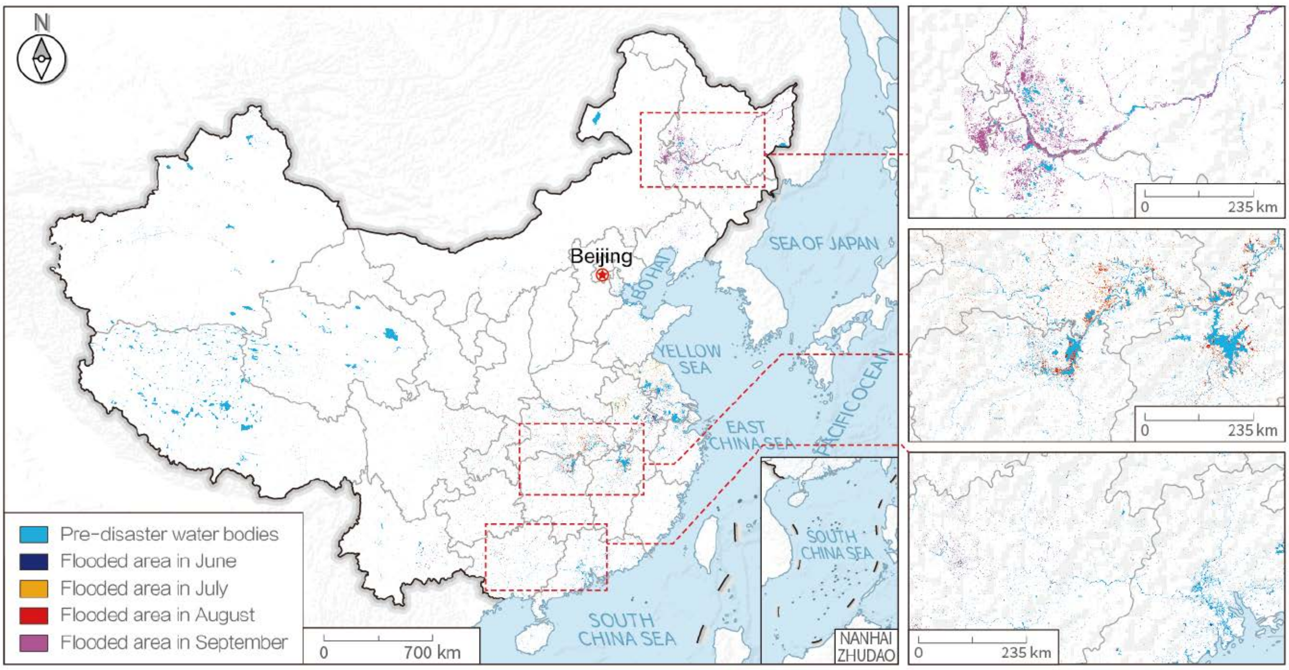


Figure 6-1 Spatial distribution map of flooded areas in China in 2020

SDG 13

flooding since 1998 first hit mainly the Pearl River Basin in June, and then the Huaihe River Basin in July, the Yangtze River Basin and the Yellow River Basin in August, and the Songliao River Basin in September.

Since 2010, the indicator of the number of people affected by flooding in China has shown a significant downward trend. After the implementation of the Sendai Framework (2016–2021), the annual average number of deaths, missing persons, and affected population per 100,000 people due to flooding in China decreased noticeably by 59.8%, 74.2%, and 44.6%, respectively (Figure 6-2a). Additionally, the areas of farmland affected and completely destroyed, as well as the direct economic losses as a proportion of GDP, decreased by 34.0%, 20.8%, and 41.0% respectively, compared to the pre-implementation period (2010–2015) (Figure 6-2b).

China has implemented effective flood defense measures, resulting in remarkable achievements in flood prevention and disaster reduction. To ensure safety and reduce flood disaster losses, China adheres to the principles of "systematic, coordinated, scientific, and safe" for monitoring and early warning, consultation and responses, flood control and dispatch, and rescue support. During the 2021 flood season, a total of 4,347 large and medium-sized reservoirs were used for flood control, and 11 national flood detention and retention basins were activated to divert, detain, and retain floodwater. Additionally, 1,494 urban areas and 1,689,400 hectares of farmland were protected from inundation, preventing the displacement of 15.246 million people and effectively ensuring safety and reducing disaster losses. Due to the implementation of proactive defense measures from 2010 to 2021, the average annual area of farmland protected from inundation was 2.8873 million hectares, and reduction in the average annual number of affected population was approximately 25.955 million people (Figure 6-2c).

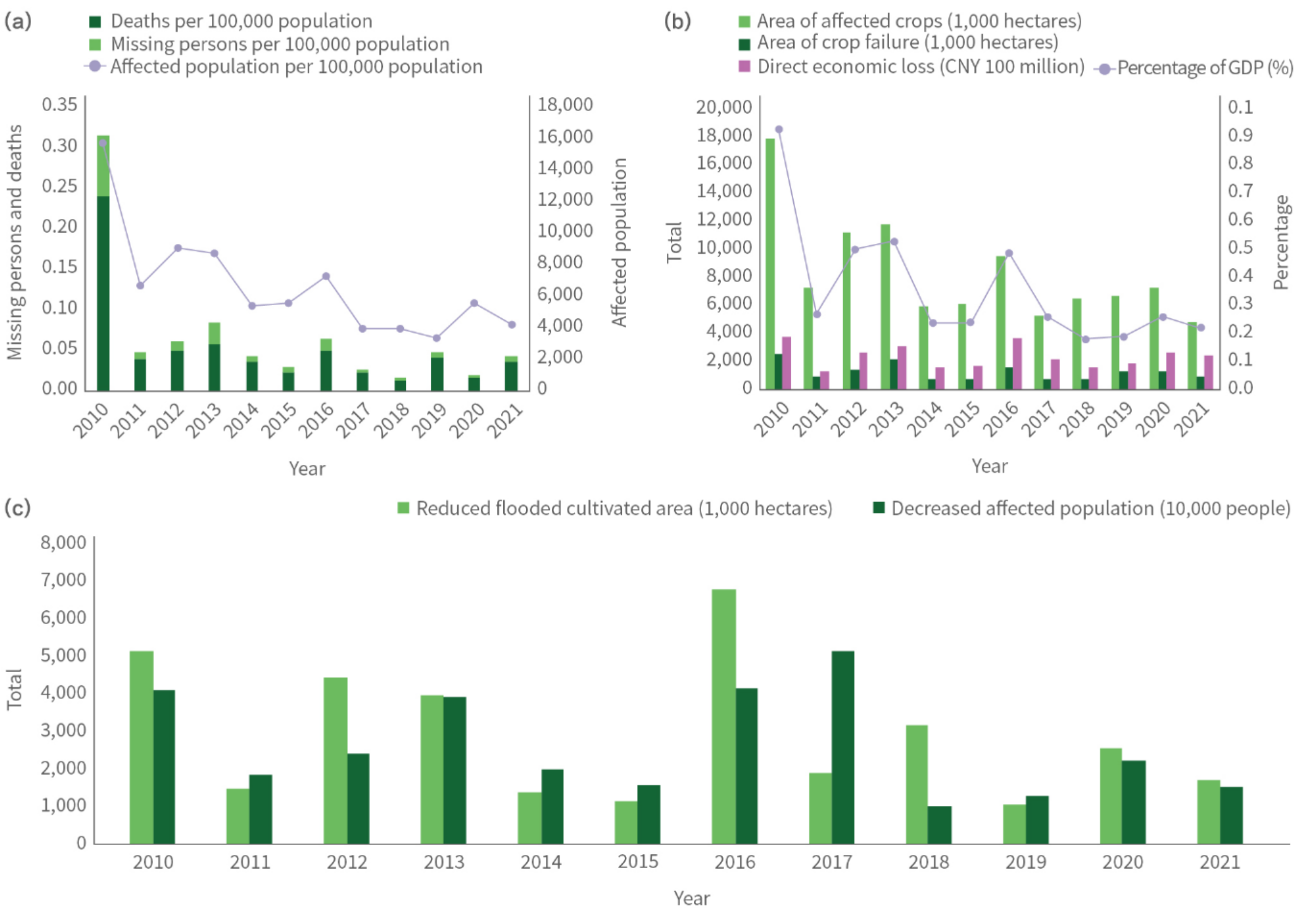


Figure 6-2 Changes in flood disaster loss in China, 2010–2021. (a) Deaths, missing persons, and affected population; (b) Area of affected crops, crop failure, and direct economic loss; (c) Reductions in flooded cultivated area and affected population due to flood control measures

Note: Due to missing data, the reduction of affected populations in 2020 and 2021 were calculated based on population whose displacement was prevented.

Actively Addressing Climate Change

An effective response to climate change requires the formulation of long-term national strategies and decision-making supported by scientific evidence. SDG 13.2, with its indicators 13.2.1 concerning climate change response strategies and 13.2.2 concerning greenhouse gas emissions, aims to incorporate climate change measures into national policies, strategies, and plans. To achieve the temperature control goals set by the *Paris Agreement*, countries have proposed their own strategies, plans, and timelines for climate change mitigation through emission reduction. However, evaluating the effectiveness of these emission reduction measures requires scientific, timely, and accurate high spatiotemporal resolution basic data, with one of the most crucial elements being the accurate quantification of greenhouse gas sources and sinks.

China's Climate Change Strategies and Actions

SDG 13.2: Integrate climate change measures into national policies, strategies and planning

SDG 13.2.1 monitors and guides the policy actions taken by countries based on the number of countries with nationally determined contributions, long-term strategies, national adaptation plans and adaptation communications, as reported to the secretariat of the United Nations Framework Convention on Climate Change (UNFCCC). China has consistently attached great importance to addressing climate change. Climate change actions in China have been government-led with multi-stakeholder participation. However, there has not been a comprehensive evaluation of China's progress in SDG 13.2.1. In this study, a data set on China's climate change policy actions from 2007 to 2023 was constructed, and an assessment of the implementation progress of this indicator in China was conducted using a text quantification method (Zheng, 2021).

China submitted its NDCs and long-term strategies to the secretariat of UNFCCC. In 2007, China issued its first policy document on climate change, the *National Program for Addressing Climate Change*, emphasizing a response to climate change within the framework of sustainable development and giving equal emphasis to mitigation and adaptation. In 2015, China submitted *Enhanced Actions on Climate Change: China's Intended Nationally Determined Contributions* to the secretariat of UNFCCC and in 2021, it submitted *China's Achievements, New Goals and Measures for Nationally Determined Contributions* and *China's Mid-Century Long-Term Low Greenhouse Gas Emission Development Strategy.*

China has also released National Climate Change Adaptation Strategy, coordinating efforts for climate change adaptation nationwide. In 2013, China issued its first strategic plan specifically focusing on climate change adaptation, the *National Climate Change Adaptation Strategy*, signifying the elevation of climate change adaptation to the level of national strategy. In 2022, *National Climate Change Adaptation Strategy 2035*, jointly issued by 17 government departments, was released, reflecting China's prioritization

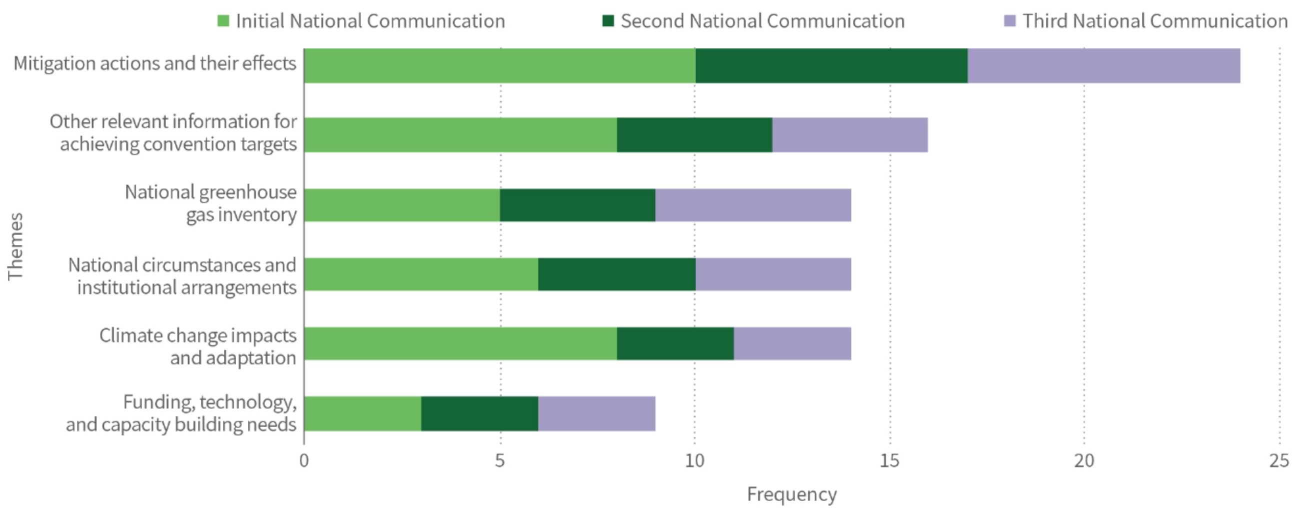


Figure 6-3 Theme distribution of China's three national communications on climate change

of proactive climate change adaptation as one of the key focuses of its climate actions. During the 13th Five-Year Plan period, local governments had formulated climate change-related plans to guide the implementation of climate change mitigation and adaptation efforts. A series of policies and measures to enhance climate change adaptation capabilities were issued in various sectors, including agriculture, water resources, forestry, human health, disaster prevention and reduction, with the aim of enhancing resilience to climate change in natural ecosystems and economic and social sectors. Currently, provinces are formulating provincial climate change adaptation action plans based on the *Guidelines for the Preparation of Provincial Climate Change Adaptation Action Programs.*

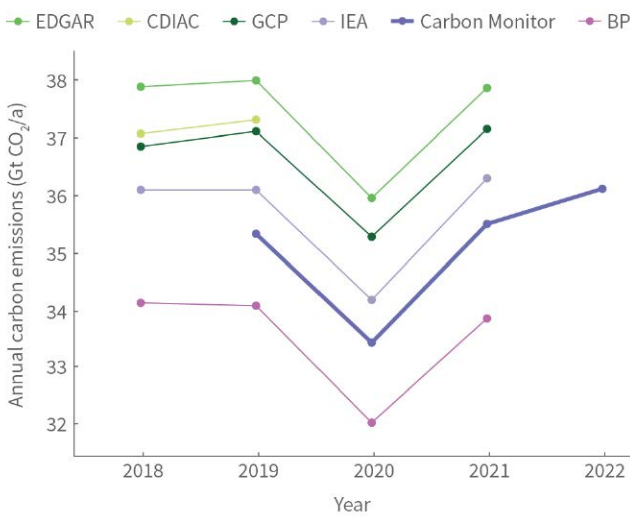
China actively fulfills its international obligations and communicates its actions and achievements in addressing climate change to the international community. As a non-Annex I Party to the UNFCCC, China has fully disclosed its actions and achievements in addressing climate change to the international community. So far, China has submitted several documents to the UNFCCC secretariat, including the *Third National Communication on Climate Change* and the *Second Biennial Update Report on Climate Change*, and completed the *Fourth National Communication on Climate Change* and the *Third Biennial Update Report on Climate Change,* demonstrating significant progress in mitigation actions (Figure 6-3).

Global Real-Time Carbon Emissions

SDG 13.2: Integrate climate change measures into national policies, strategies and planning

Carbon emission sources in countries around the world are divided into six main sectors: electricity, industry, residential consumption, surface transport, aviation, and maritime. By utilizing multiple sources of information such as statistical data, satellite remote sensing data, and field observation data, a method based on sector activity levels was developed to quantitatively estimate near-real-time global carbon emissions for evaluating their spatiotemporal dynamic variations during the period from 2019 to 2022. This method establishes a linear relationship between carbon emissions and activity intensity (e.g., fuel consumption, electricity generation, travel distance) and allows for near-real-time estimation of carbon emissions for each sector within the uncertainty range, resulting in a daily data set of carbon emissions by sector for major countries worldwide from 2019 to 2022. These data serve as constraints for daily carbon emission estimates at the national level and are combined with NO_2 satellite observation concentration values to correct the spatial distribution of carbon emissions at daily scales, providing spatially-resolved global near-real-time carbon emission data.

Other global databases, including the Emissions Database for Global Atmospheric Research (EDGAR), the Carbon Dioxide Information Analysis Center (CDIAC), the International Energy Agency (IEA), the Global Carbon Project (GCP), and British Petroleum (BP), also report



↑ Figure 6-4 Comparison of global carbon emission data from different databases, 2018–2022

↑ Figure 6-5 Global daily-scale carbon emission dynamics, 2019–2022

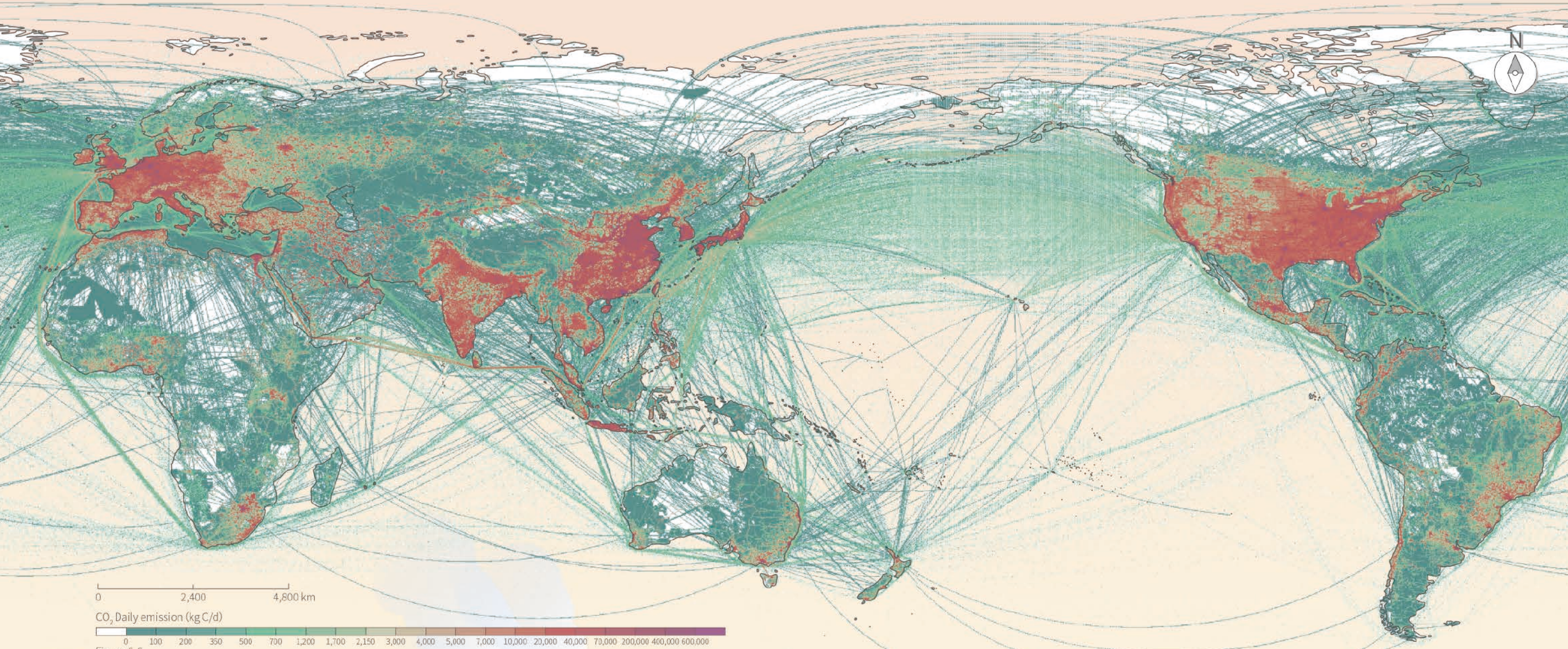


Figure 6-6

Global near-real-time daily-scale carbon emission map, 2022 (0.1°×0.1°)

annual global carbon emissions, but with a time lag of one to three years. Furthermore, the differences in accounting scopes among these databases result in discrepancies in emission estimates (Figure 6-4). The Carbon Monitor's emission accounting scope (fossil fuel combustion and cement production processes) is the same as that of GCP and CDIAC, but is approximately 5% lower.

Global annual carbon emissions exhibit significant seasonal variations. The daily-scale dynamic changes in global carbon emissions from 2019 to 2022 are shown in Figure 6-5. Carbon emissions are highest in winter (December) and lowest in spring (April), with a less pronounced increase in summer and a further rapid increase in autumn. This pattern is related to the fact that a large proportion of the global population is concentrated in the northern hemisphere, where there is a demand for heating in winter and cooling in summer. Due to different geographical locations, there are variations in the seasonal characteristics of monthly emissions for different countries. European Union member countries and Russia are located in the mid to high latitudes of the northern hemisphere and belong to typical temperate regions. They experience a significant seasonal pattern of higher emissions in winter and lower emissions in summer, influenced by the need for heating in winter. China and the United States are mostly located in temperate and subtropical climate zones, showing smaller peaks in emissions during winter and summer, driven by the demand for heating in winter and cooling in summer. India is situated in a tropical region with high temperatures throughout the year, resulting in no significant seasonal variation in carbon emissions.

The impact of the COVID-19 pandemic on carbon emissions has largely disappeared. Global carbon emissions data show that human-caused carbon emissions experienced a sharp decline of 5.4% (1.9 Gt CO_2) in 2020 due to the impact of the COVID-19 pandemic compared to 2019. However, in 2021, carbon emissions rebounded to levels close to those before the pandemic, increasing by 6.3% (2.1 Gt CO_2). In 2022, global CO_2 emissions increased by 1.5% compared to 2021, reaching 36.1 Gt CO_2. If the world maintains the emission levels of 2022, the remaining carbon budget under the 1.5 ℃ warming limit will be depleted within the next 2 to 7 years (with a 67% likelihood).

The global near-real-time carbon emissions map at a daily scale (Figure 6-6) covers over 90% of countries and regions worldwide, with a spatial resolution of 0.1° × 0.1°. It can reflect global carbon emission hotspots and analyze the spatial-temporal patterns of carbon emissions on annual, seasonal, monthly, and weekly scales. Additionally, the carbon emissions map can focus on more detailed spatial scales to study the spatial-temporal distribution trends of carbon emissions at the provincial and city levels.

Greenhouse Gas (CO_2, CH_4, and N_2O) Fluxes in Global Terrestrial Ecosystems

SDG 13.2 Integrate climate change measures into national policies, strategies and planning

Compared to other sectors in the Intergovernmental Panel on Climate Change (IPCC) Guidelines for National Greenhouse Gas Inventories, the accounting for greenhouse gas fluxes from terrestrial ecosystems has the highest uncertainty. The highest-level accounting method recommended by the Guidelines is to use terrestrial ecosystem models for national-scale assessments. In this study, the Integrated BIosphere Simulator (IBIS) model (Yuan *et al*., 2014) was used to calculate global greenhouse gas (CO_2, CH_4, and N_2O) fluxes from terrestrial ecosystems. The IBIS model fully couples the biological, chemical, and physical processes of terrestrial ecosystems and is one of the few models in the world capable of simultaneously simulating fluxes of all three greenhouse gases. Based on IBIS, the latest land use change and vegetation distribution data were integrated to improve the simulation accuracy. IBIS model simulations of N_2O and CH_4 fluxes have been significantly superior to other mainstream international models, as validated at multiple global sites.

The three greenhouse gases show different source-sink patterns in the global terrestrial ecosystems. For CO_2, the global terrestrial ecosystems acted as a significant carbon sink (i.e., absorbing CO_2 from the atmosphere) from 1980 to 2022, with an average intensity of 2.36 Pg C/a (Figure 6-7a). However, for CH_4 and N_2O, the global terrestrial ecosystems were sources of emissions to the atmosphere,

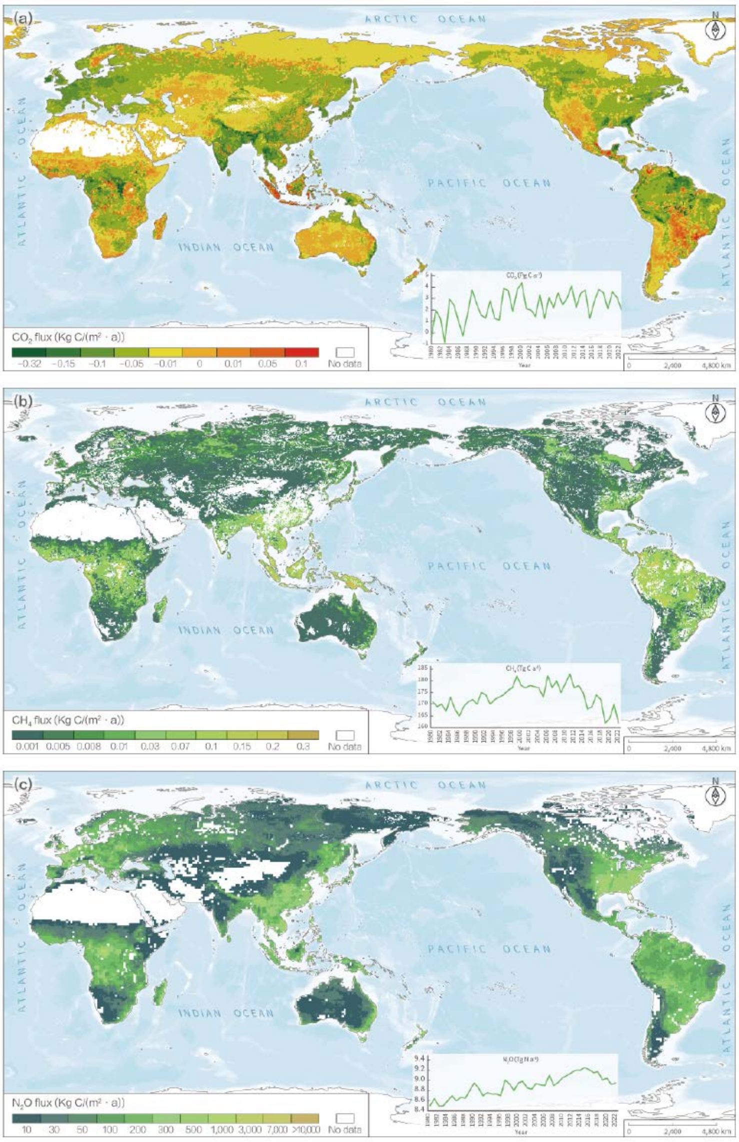


Figure 6-7 Global average fluxes of three greenhouse gases, 2010–2022. (a) CO_2 flux (negative values indicate carbon sinks, positive values indicate carbon sources); (b) CH_4 emission flux; (c) N_2O emission flux

with average emission intensities of 173 Tg C/a and 8.9 Tg N/a, respectively, from 1980 to 2022 (Figures 6-7b and 6-7c). The long-term trends of these three greenhouse gases also showed significant differences. The carbon sink exhibited a significant increasing trend from 1980 to 2000, with an annual increase rate of 0.17-0.19 Pg C/a. However, since 2000, the increase in carbon sink from global terrestrial ecosystems has stagnated and even displayed a non-significant decreasing trend. CH_4 emissions showed an increasing trend followed by a decrease, with the turning point occurring around 2012. N_2O emissions significantly increased from 1980 to 2016 and began to decline after 2016.

China's terrestrial ecosystems play an important role in the global greenhouse gas source-sink patterns. From 1980 to 2022, the average carbon sink intensity of China's terrestrial ecosystems accounts for 11% of the global carbon sink. Particularly noteworthy is that, thanks to large-scale ecological projects implemented in China, the increase rate in its terrestrial carbon sink has exceeded the global carbon sink increase rate. In the period between 2010 and 2022, China's terrestrial carbon sink accounted for 15.95% of the global total. China's average CH_4 emissions from terrestrial ecosystems has shown a fluctuating trend. As for N_2O emissions from China's terrestrial ecosystems, there has been a significant decline in emissions due to the implementation of environmental protection policies aimed at reducing the use of chemical fertilizers in farmlands.

Strengthening Climate Change Education

Mitigating climate change requires clear national strategies and broad public participation. SDG 13.3.1 aims to understand the extent of mainstreaming of (i) global citizenship education and (ii) sustainable development education in (a) national education policies, (b) curricula, (c) teacher education, and (d) student assessment. In China, social media platforms like Sina Weibo, with 586 million monthly active users, are becoming important platforms for climate change information exchange, opinion formation, and engagement beyond formal education.

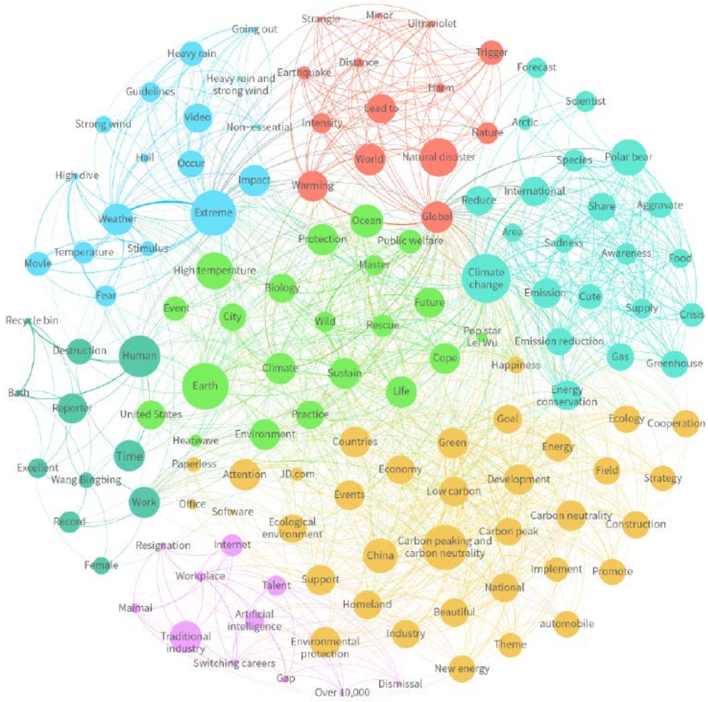
Social Media Communication on Climate Change in China

SDG 13.3: Improve education, awareness-raising and human and institutional capacity on climate change mitigation, adaptation, impact reduction and early warning

The case study collected data from January 1 to December 31, 2022, using random sampling of one day within a week through Python programming to extract relevant posts containing keywords such as climate change, global warming, extreme weather, carbon peak, carbon neutrality, etc., from Sina Weibo (Figure 6-8). After cleaning and removing duplicates and irrelevant data from the posts, a total of 53,788 rows of valid data for analysis were obtained. Data analysis revealed the following:

There are significant differences in the dissemination of climate change information across China's seven geographical regions, with strong dissemination observed in the three major economic belts. South China, North China, and East China, which are economically developed regions, show higher dissemination scores, all above 80. In the three major economic belt regions, i.e., the Pearl River Delta, the Yangtze River Delta, and Beijing-Tianjin-Hebei, the public is active in following, sharing and commenting on climate change topics, and the level of active participation is highest in South China, with a dissemination score of 85.03. In contrast, in the Northwest, Central China, and Northeast regions, the public tends to passively receive information rather than actively setting climate change issues, resulting in relatively lower numbers of active users participating in comments and sharing.

Economic development and the effect of young influencers are two driving factors for the dissemination of climate change issues. The introduction of carbon peak and carbon neutrality goals has effectively sparked public interest in climate change in China. Machine learning methods were used to extract common themes related to climate change from the Weibo post data. It was found that the public generally views climate change as an economic issue and emphasizes the need to reduce carbon emissions through economic and technological means. The introduction of China's carbon peak and carbon neutrality goals triggered discussions on the transition of traditional industries and the demand for talents in carbon-related industries in the job market. It was also observed that Chinese people have a complex perspective on climate change—they perceive it as both a threat and an important opportunity for economic transformation. In addition to industry discussions, in public-oriented communication, celebrities as endorsers or public ambassadors have a significant influence on promoting carbon peak and carbon neutrality goals, especially in raising awareness and encouraging active climate action among



↑ Figure 6-8 The interrelation among keywords in Weibo posts (Node size corresponds to keyword frequency, while the color of each node reflects distinct category clusters. Connecting lines depict co-occurrence relationships between keywords.)

SDG 13

young people in the educational stage.

Chinese social media users are confident in the achievement of the country's carbon peak and carbon neutrality goals and hold a generally positive attitude towards mitigating climate change. A sentiment analysis was conducted on the extracted climate change-related weibo posts. Overall, the weibo content showed that 72.98% of the posts expressed positive sentiments, while 24.43% expressed negative ones. This indicates that the Chinese public on social media tends to follow the opinions and attitudes of mainstream media or opinion leaders, displaying an overall positive, optimistic, and confident outlook.

13 CLIMATE ACTION

Recommendations and Outlook

This chapter focuses on three main themes: reducing the impact of climate-related disasters, actively addressing climate change, and strengthening climate change education. Through the use of Big Earth Data, we achieved calculations for four SDG indicators: disaster losses (SDG 13.1.1), climate change strategies (SDG 13.2.1), greenhouse gas emissions (SDG 13.2.2), and climate change education (SDG 13.3.1). We also provided corresponding spatiotemporal data products. Based on the results of continuous monitoring of climate action-related indicators, a midterm evaluation was conducted. The findings show that China's disaster prevention and reduction strategies are relatively comprehensive and have shown positive results. The strategies for carbon peak and carbon neutrality, and climate change response strategies, have been gradually improved, but the implementation of these tasks remains challenging.

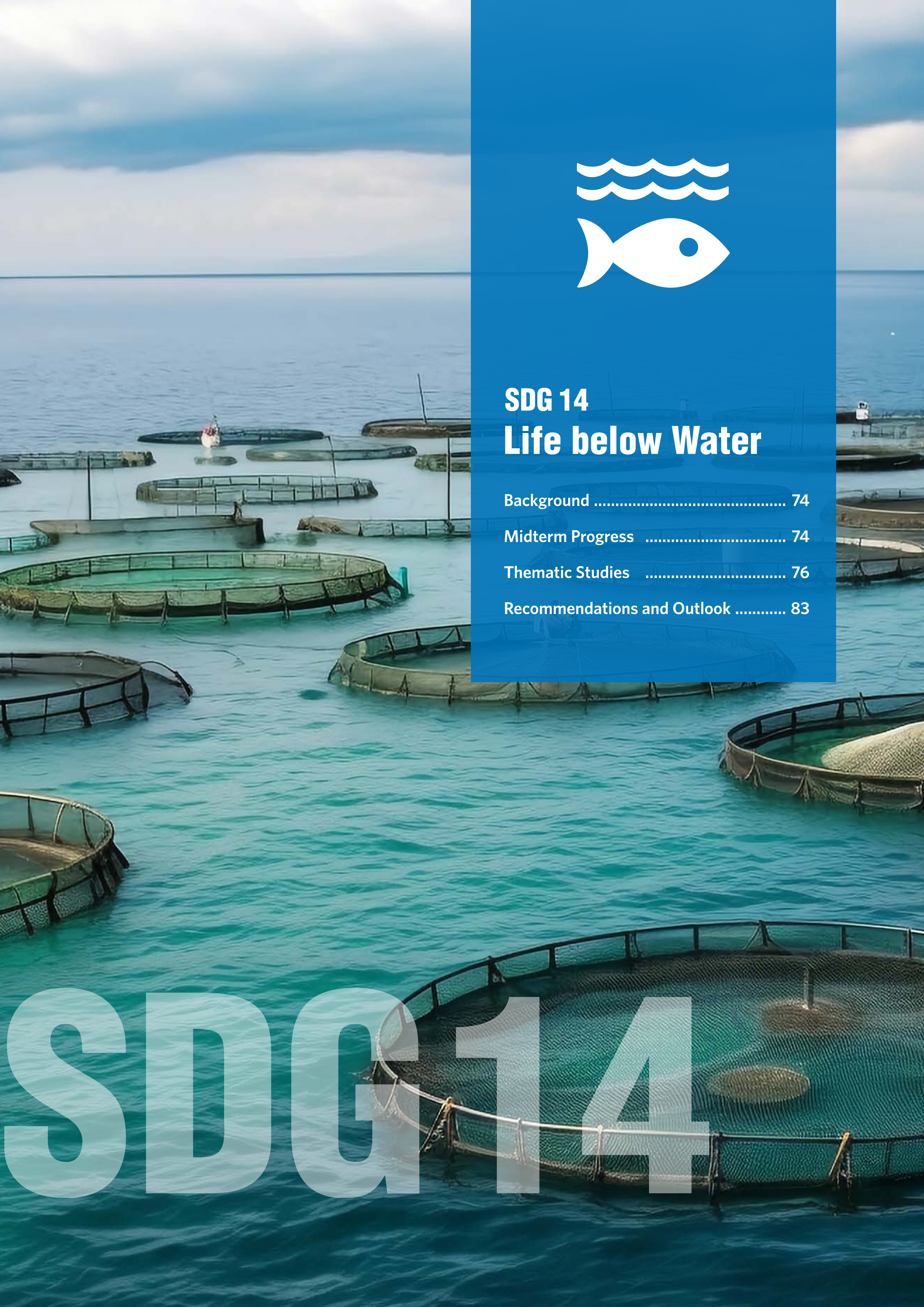
Based on the data and conclusions from this chapter, we propose the following recommendations:

1. The impact of floods and waterlogging has been significantly reduced in China thanks to the flood monitoring, forecasting, and warning system, large and medium-sized reservoirs, flood detention areas, and other flood control and management systems. To better cope with floods and waterlogging under extreme climate conditions, further efforts are needed to enhance three-dimensional monitoring supported by data from space, sky and ground and improve the accuracy of forecasting and early warning.

2. Concerning SDG 13.2.2, it is suggested that this indicator be modified from annual greenhouse gas emissions to emissions per capita or emissions per unit of GDP in order to be more suitable for evaluating countries of different sizes.

3. Climate change literacy and media literacy education should be strengthened among young people. Emphasis should be placed on media-driven dissemination of climate change scientific knowledge. It is essential to cultivate enthusiastic young leaders in carbon peak and carbon neutrality actions. Education and dissemination are the dual drivers for the early achievement of the positive guidance and mainstreaming goals of SDG 13.3.1.

Some progress has been made in China and the world in disaster prevention and reduction under SDG 13, and attention should now be focused on the implementation progress of greenhouse gas emission reduction. It is necessary to strengthen data monitoring capabilities for greenhouse gas emissions, and also to make robust policies to accelerate emission reduction progress. Additionally, efforts should increase in forest protection and farmland management to enhance the capacity of ecosystems to sequester greenhouse gases.



SDG 14
Life below Water

SDG14

14 LIFE BELOW WATER

Background

The ocean plays a crucial role in regulating the global water cycle, climate, and biodiversity, as well as providing habitat for many important species. Marine products supply at least 20% of animal protein to around 3.1 billion people globally, making it particularly important for livelihoods in economically disadvantaged coastal areas and small island developing countries.

SDG 14, one of the 17 transformative goals under the 2030 Agenda, aims to conserve and sustainably use the ocean, sea and marine resources. However, from a global perspective, the implementation of most targets under SDG 14 has not been ideal. *The Second World Ocean Assessment (WOA II)*, released by the United Nations on April 21, 2021, indicated that many pressures from human activities continue to degrade the ocean since the WOA I in 2015. In response to the current ocean emergencies, the Lisbon Declaration, adopted at the United Nations Ocean Conference in 2022, called for increased scientific and innovative actions, emphasizing the need for ambitious, determined and timely actions to improve the health, sustainability and resilience of marine and coastal ecosystems. The declaration urged parties to take further measures in areas such as strengthening data collection, reducing greenhouse gas emissions, and innovating financing mechanisms to achieve sustainable ocean economies.

In the United Nations Secretary-General's special edition report titled *Progress towards the Sustainable Development Goals: Towards a Rescue Plan for People and Planet* issued on April 27, 2023, the overall assessment of SDG 14 implementation shows that while some progress has been made globally in expanding marine protected areas and combating illegal, unreported, and unregulated fishing activities, destructive trends in marine health have not weakened and the ocean continues to face threats from acidification, eutrophication, declining fish stocks, and rising plastic pollution; approximately 50% of the indicators have stagnated or regressed, indicating the urgent need for more coordinated and accelerated efforts (UN, 2023c).

Reports of the past four years utilized technologies and methods such as Big Earth Data to conduct in-depth research on relevant targets and indicators, such as SDG 14.1 and SDG 14.2, for which methods are available but not data. Attempts were made to explore ways to obtain relevant data for China and globally typical regions and calculating models to compensate for the lack of data from the United Nations. Meanwhile, long-term dynamic monitoring and analysis of targets with distinctive features in the Chinese region, such as SDG 14.5 and SDG 14.7, had been conducted. In this year's report, by analyzing the dynamic changes in coastal microplastics, seagrass meadows, coral reef coverage, bay ecosystem health, and marine raft culture, we further improved the monitoring methods for SDG 14 indicators, built corresponding technical and model systems, and provided refined monitoring and assessment products. Furthermore, by integrating the achievements of previous reports, we conducted a midterm progress assessment of SDG 14 in China to better understand the progress and take measures to advance its realization.

14 LIFE BELOW WATER

Midterm Progress

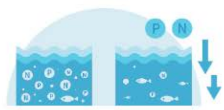
Based on the 2019–2022 reports and this chapter's research results on SDG 14, the midterm progress has been evaluated on targets such as preventing and reducing marine pollution (SDG 14.1), protecting marine and coastal ecosystems (SDG 14.2), conserving coastal and marine areas (SDG 14.5), and sustainable management of aquaculture (SDG 14.7). The assessment based on Big Earth Data indicates that, guided by the principles of green development and the strategy to become a maritime power, China has made significant efforts to promote the implementation of SDG 14 and has achieved a series of outcomes. The specific progress is as follows:

1. In preventing and reducing various types of marine pollution (SDG 14.1), the research in the 2022 report showed that in China's eastern coastal areas, the long-term trend of different nutrients exhibited significant reductions from 2009 to 2019, including dissolved inorganic nitrogen, dissolved inorganic phosphorus, and silicate concentrations. From 2015 to 2022, the overall area of eutrophic waters in

China's jurisdiction showed a decreasing trend (Ministry of Ecology and Environment of the People's Republic of China, MEE, 2022). The 2020 report revealed that the abundance of floating debris in the 22 typical regions along China's coasts decreased by approximately 25% in 2018 compared to the average value from 2010 to 2014. The current report's research indicates that the average abundance of microplastics in China's coastal waters was at a low-to-medium level from 2018 to 2021.

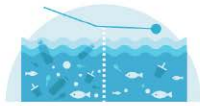
2. In protecting marine and coastal ecosystems (SDG 14.2), the 2022 report revealed that China's coastal wetlands played an increasingly important role in typhoon preparedness and disaster reduction. It was estimated that the typhoon preparedness value of China's coastal wetlands was CNY 92.69 billion in 2010, which increased to CNY 211.9 billion in 2015 and reached a high of CNY 295.97 billion in 2020. The 2021 report's research indicated that from 2015 to 2020, China's mangrove area increased by 16%, with the most significant increase observed in Guangdong and Guangxi coasts, and mangroves within nature reserves were well protected and restored. Furthermore, the overall health of China's typical bay ecosystems was assessed by analyzing the current status and trends of various ecosystem elements. The research

SDG 14 Life Below Water: China Midterm Progress



From 2015 to 2022, the area of eutrophic sea areas under the jurisdiction of China showed an **overall downward trend**[1,2].

SDG 14.1.1



In 2018, the abundance of floating waste in China's coastal waters decreased by approximately **25%** compared with the average level in 2010–2014[3].

SDG 14.1.1

In 2010, the value of typhoon preparedness services of coastal wetlands in China was CNY 92.69 billion, and reaching **CNY 295.97 billion** in 2020[1].

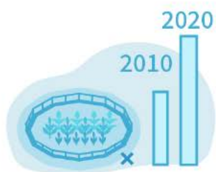
SDG 14.2.1

From 2015 to 2020, China's mangrove area had a net increase of **16%**[4].

SDG 14.2.1

In 2021, the ecosystem health of Jiaozhou Bay in Qingdao, Shandong was **the best in the nearly two decades** (2003–2021)[5,6].

SDG 14.2.1

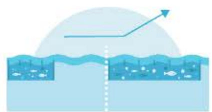


From 2010 to 2020, the pace of returning enclosures to the sea and wetlands in coastal China **continued to increase**[1].

SDG 14.5.1

The area of coastal aquaculture ponds in China shows a **continuous downward trend in general**[1,4].

SDG 14.7.1



From 2015 to 2021, the area of raft culture in China experienced **orderly growth**, exhibiting a trend of distribution away **from the coastline**[3,5].

SDG 14.7.1

Notes:
1.Big Earth Data in Support of the Sustainable Development Goals (2022); 2.Report on the State of the Ecology and Environment in China 2022; 3.Big Earth Data in Support of the Sustainable Development Goals (2020); 4.Big Earth Data in Support of the Sustainable Development Goals (2021); 5.Big Earth Data in Support of the Sustainable Development Goals (2023); 6.Big Earth Data in Support of the Sustainable Development Goals (2019).

SDG 14

from the 2019, 2020 and the current reports showed that the Jiaozhou Bay in Qingdao, Shandong, Sishili Bay in Yantai, Shandong, and Daya Bay in Huizhou, Guangdong, among other typical bays in coastal China, currently have a good ecological health status. Particularly, the ecological health of the Jiaozhou Bay has been improving since 2010, reaching its highest level in 2021 in the nearly two decades from 2003 to 2021.

3. In conserving coastal and marine areas (SDG 14.5), the Chinese government has consistently attached great importance to the control and management of land reclamation. In 2018, the *Notice of the State Council on Strengthening Coastal Wetlands Protection and Land Reclamation Control* called for prioritizing ecological protection, green development, and the strictest environmental conservation system, effectively shifting the working approach from "claiming land from the sea" to strict control of new land reclamation, and strengthening ecological conservation and restoration. As a result, marine resources are under strict protection, effectively restored, and efficiently utilized. The 2022 report's research showed that from 2010 to 2020, the pace of returning enclosures to the sea and wetlands in coastal China continued to increase, with the most significant increase observed from 2018 to 2020. China's efforts in controlling and managing land reclamation and restoring coastal wetlands have achieved significant results.

4. In sustainable management of aquaculture and related areas (SDG 14.7), China's aquaculture of specialty aquatic products has continued to expand, and the development of eco-friendly aquaculture models has rapidly progressed. The scale and intensification of aquaculture have gradually increased. The research in the 2021 and 2022 report showed that driven by policies such as reverting mariculture enclosures to wetlands, the overall area of such enclosures in China exhibited a continuous decreasing trend. The annual average area returned from mariculture breeding enclosures in coastal China was about 3.72 km^2 from 2010 to 2015, 4.77 km^2 from 2015 to 2018 and 21.62 km^2 from 2018 to 2020. Meanwhile, the 2020 report and the current report's research showed that from 2015 to 2021, China's marine raft culture area experienced orderly growth. While the area of raft culture within the boundaries of the coastal ecological conservation red line remained stable on the whole, there was a trend of its distribution farther away from the coastline.

Thematic Studies

Reducing Marine Pollution

The Chinese government attaches great importance to the prevention and control of marine pollution, implementing a comprehensive set of laws and regulations that form a robust foundation for mitigating various forms of marine pollution. This theme conducted research on the distribution and temporal variations of microplastics in China's coastal waters, providing data and theoretical support for the objective evaluation of the impact of microplastics on the marine environment and human health.

Analysis of the Distribution Characteristics and Temporal Variation of Microplastics in China's Coastal Waters

SDG 14.1: By 2025, prevent and significantly reduce marine pollution of all kinds, in particular from land-based activities, including marine debris and nutrient pollution

As a new type of pollutant, marine microplastics have become one of the hotspots of international research (Gu *et al*., 2022; Sun *et al*., 2022). On March 2, 2022, the fifth resumed session of the United Nations Environment Assembly adopted the *Draft Resolution on Ending Plastic Pollution*, a legally binding resolution aims to promote a global clean-up of plastic pollution. This case, focusing on SDG 14.1, integrates microplastic detection results from different monitoring stations in China's coastal waters from 2015 to 2022, data from the *Bulletin of Marine Ecology* *and Environment Status of China* (MEE, 2018–2021), and other relevant Big Earth Data from reputable international environmental journals (Sun *et al*., 2018; Zhu *et al*., 2018; Zhang *et al*., 2020a; Liu *et al*., 2022). The study examines the presence and characteristics of microplastics in China's coastal waters, including their abundance, size, and types, and investigates the distribution patterns of microplastics in these waters. By analyzing the annual abundance distribution of microplastics, the study evaluates how the levels of microplastics in China's coastal waters have changed over the years.The microplastic samples in seawater were mainly collected using trawl net samples, and microplastic types were determined through microscopic infrared spectroscopy analysis.

The results show that there were difference in the abundance of microplastics floating on the sea surface of different sections of China's coastal waters in 2021 (Figure 7-1a). The average abundance of floating microplastics on the sea surface measured through monitoring sections in the Bohai Sea, Yellow Sea, East China Sea and Northern South China Sea was 0.74 items/m^3, 0.54 items/m^3, 0.22 items/m^3 and 0.29 items/m^3 respectively. Floating microplastics are mainly fibers, foams, granules and fragments. The main microplastic types are Polyethylene Terephthalate (PET), Polypropylene (PP), Polystyrene (PS) and Polyethylene (PE). From 2018 to 2021, the average abundance of microplastics floating on the sea surface of the monitoring sections in the Chinese offshore were 0.42 items/m^3(2018), 0.54 items/m^3(2019), 0.27 items/m^3(2020) and 0.44 items/m^3(2021), respectively (Figure 7-1b). Compared with the results of similar international surveys in recent years, the average abundance of floating microplastics in China's coastal waters was at a low-to-medium level.

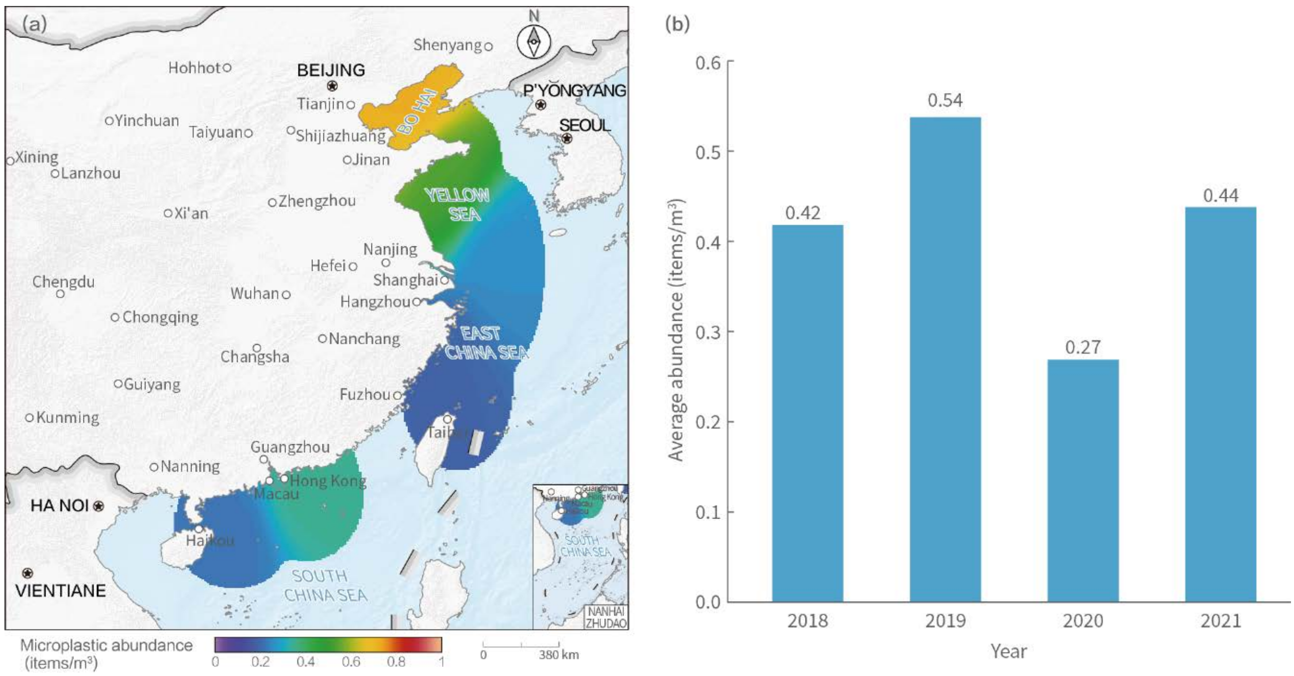


Figure 7-1 Distribution and interannual variation of microplastic abundance in China's coastal waters. (a) Microplastic abundance distribution in China's coastal waters in 2021; (b) Variation of average abundance of floating microplastics on the sea surface of China's offshore monitoring section

Preserving Marine Ecosystems

Marine ecosystems, consisting of biological communities and their interactions with the environment in the ocean, play a crucial role in supporting life on Earth and are essential for sustainable development of society and the environment. This theme utilizes Big Earth Data technology to fill data gaps and achieve precise monitoring and analysis of changes in typical marine ecosystems such as seagrass meadows and live coral reefs. It also aims to objectively assess the health status of typical marine bay ecosystems in China.

Dynamic Monitoring of Seagrass Meadow Distribution in Coastal China

SDG 14.2: By 2020, sustainably manage and protect marine and coastal ecosystems to avoid significant adverse impacts, including by strengthening their resilience, and take action for their restoration in order to achieve healthy and productive oceans

Seagrass meadows consist of extensive, connected seagrass communities and, together with their surrounding environment, form an important marine ecosystem. Ranked alongside mangroves and coral reefs, they are one of the three typical marine ecosystems and among the most productive ecosystems on Earth. In this case, field investigation and multiple sources of satellite remote sensing data are integrated, and with the aid of high-performance computing on Big Earth Data platform, machine learning models are employed to extract and analyze dynamic information about the spatial distribution of seagrass meadows in coastal China.

According to the survey results of Investigation on Important Seagrass Resources and Habitats in China's Coastal Zone (2015–2021) and remote sensing monitoring, the total area of seagrass meadows in China's coastal waters is approximately 27,010 hectares. Among them, approximately, Liaoning has an area of 3,205 hectares, Hebei 9,171 hectares, Tianjin 466 hectares, Shandong 4,193 hectares, Fujian 470 hectares, Guangdong 1,538 hectares, Guangxi 665 hectares, Hainan 6,728 hectares, and Taiwan 574 hectares (Zhou *et al.*, 2023; Li *et al.*, 2022).

Based on the Big Earth Data computing platform, the series of satellite data of Landsat, SPOT and Sentinel during the period of 1985–2020 were utilized to monitor and classify China's offshore waters through the Support Vector Machine algorithm and to obtain the information on the dynamic change of the distribution and area of seagrass meadows in the period of 1985–2020 (Figure 7-2). The results show that the area of seagrass meadows in coastal China (except Sansha City) on the whole exhibited a decreasing trend (1985–2010) followed by a slight rebound (2010–2020). Land reclamation, human pollution and exotic plants are the most important causes of seagrass meadow shrinkage. Since 2010, relevant state departments have emphasized and protected seagrass meadow ecosystems, which has led to the recovery of many key seagrass meadow areas. For example, the Caofeidian seagrass meadow, which is the largest in northern China, had been gradually decreasing in size since the 1980s due to human activities. In 2015, the relevant scientific research team began to work with the local government for its conservation and restoration (Liu *et al.*, 2016), which has resulted in a recovery of the Caofeidian seagrass meadow to the level of the 1980s.

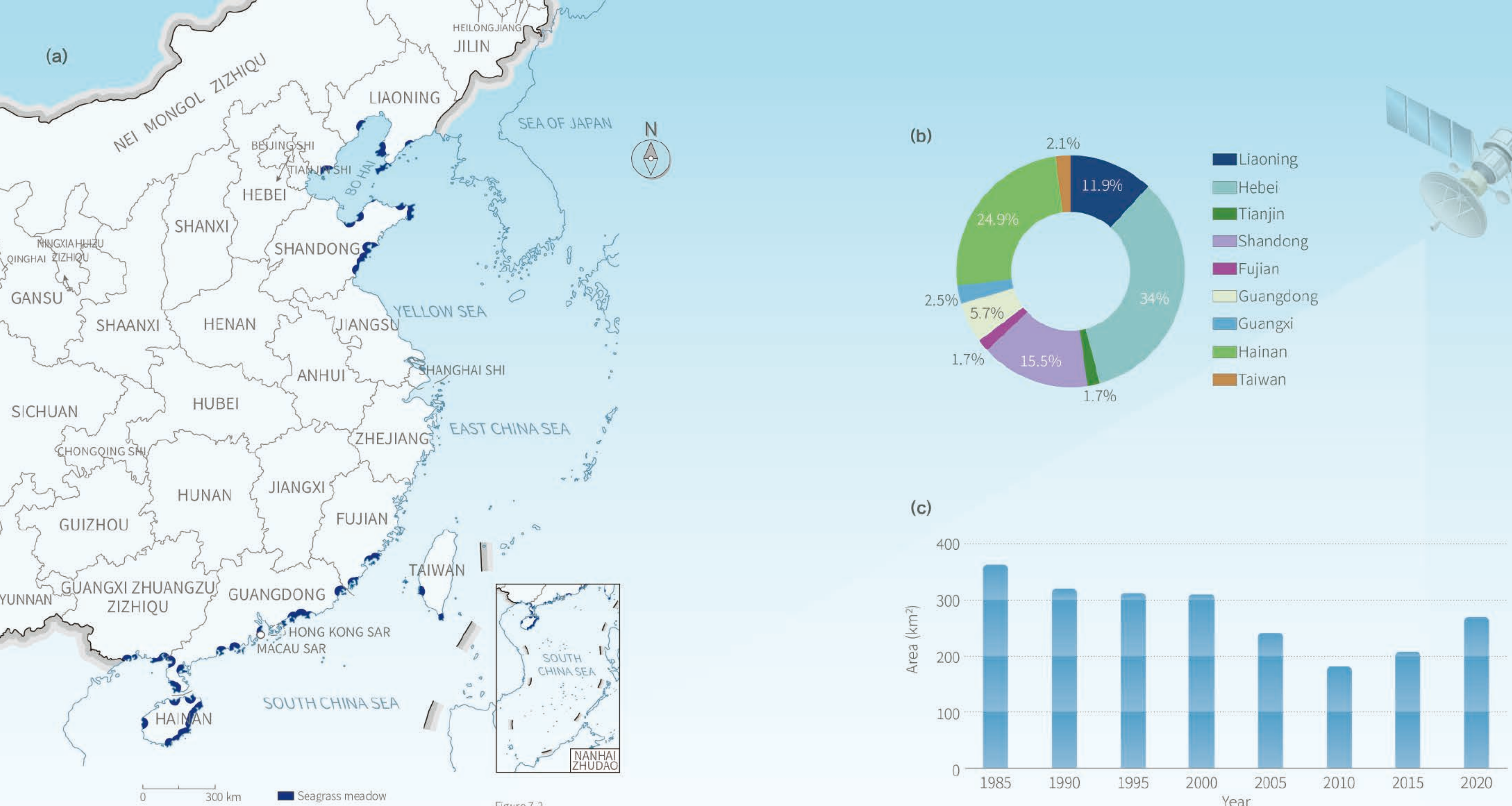


Figure 7-2

Distribution and area changes based on remote sensing monitoring of seagrass meadows in coastal China

(a) Spatial distribution of seagrass meadows in 2020

(b) Proportional area (%)of seagrass meadows in different provinces of China in 2020

(c) Changes of seagrass meadow area from 1985 to 2020

Dynamic Monitoring of Live Coral Cover in Typical Coral Reefs

SDG 14.2: By 2020, sustainably manage and protect marine and coastal ecosystems to avoid significant adverse impacts, including by strengthening their resilience, and take action for their restoration in order to achieve healthy and productive oceans

Coral reefs are sensitive and fragile ecosystems that have been rapidly degrading in recent decades under the influence of global changes. They are predicted to be the first typical marine ecosystem lost due to global changes. In this case, a remote sensing inversion model and method for live coral cover were developed based on multi-source optical remote sensing data. This allowed for the creation of global monitoring data products of live coral cover in typical regions, which can inform the planning, management, development, utilization, and protection of coral reef resources.

With the increasing availability of medium to high-resolution multispectral satellite data, the use of multispectral satellite remote sensing has great potential and prospects for dynamically monitoring live coral cover (Liao *et al.*, 2021). In this case, based on the systematic analysis of the spectral reflectance characteristics of typical corals, a model for live coral cover was constructed by considering the like second-order difference operator of the blue band. The model employed field ecological survey data and regression analysis of band ratios. The spatial extension, temporal extension, and sensor extension of the model were analyzed. The root mean square error and mean absolute error of the constructed live coral cover inversion model were 8.84% and 5.79%, respectively. This method effectively extracts live coral cover information that can inform the analysis and conservation management of coral reef ecosystems.

The overall live coral cover in typical coral reefs is in a decreasing state. Using satellite data from Landsat's Operational Land Imager (OLI) and China's Marine Satellite (HY-1C/D), the live coral cover of the Kure Atoll in Hawaii

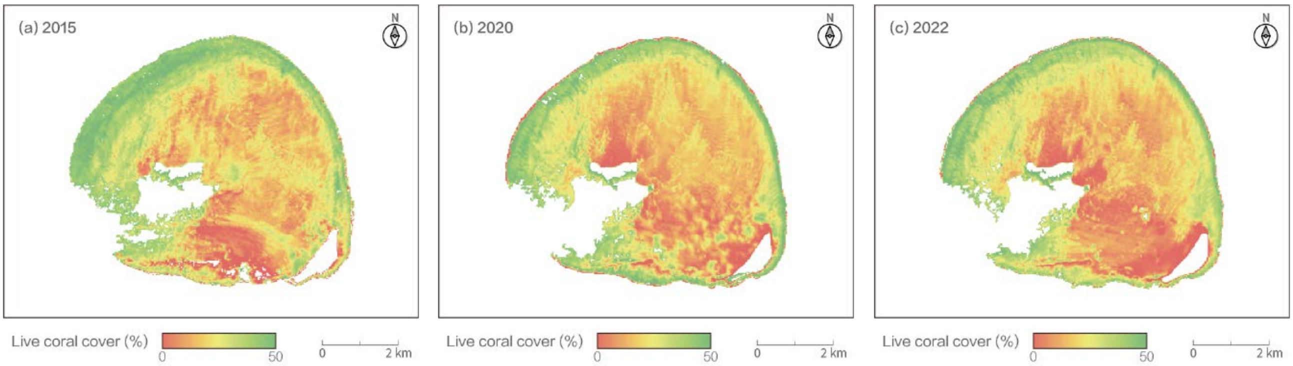


Figure 7-3 Hawaiian Reef (Kure Atoll) live coral cover. (a) 2015; (b) 2020; (c) 2022

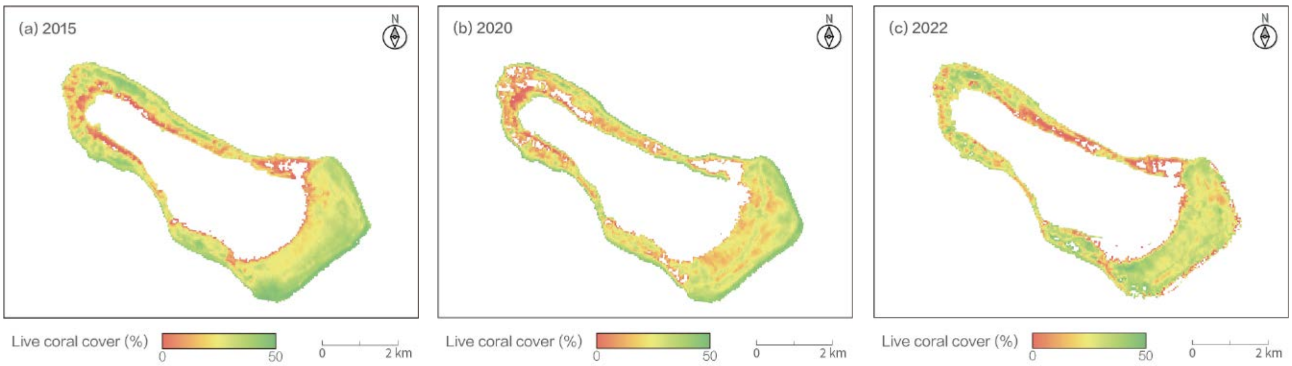


Figure 7-4 Great Barrier Reef (Unnamed Reef) Live Coral Cover. (a) 2015; (b) 2020; (c) 2022

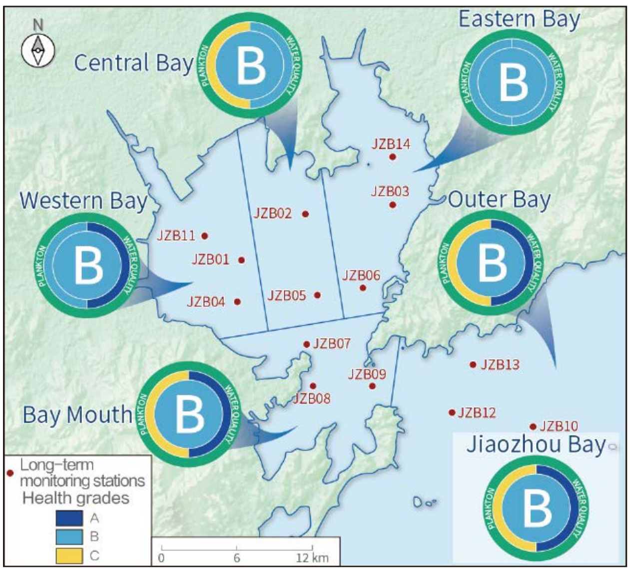
(Figure 7-3) and the Unnamed Reef in the Great Barrier Reef (Figure 7-4) were calculated for the years 2015, 2020, and 2022. The results show that both of these typical reef areas have a common trend of degradation. From 2015 to 2020, there was a significant decrease in live coral cover, and the distribution of live coral areas decreased. For Kure Atoll, the live coral cover decreased from 24.00% to 18.63%, a decline of 5.37%, which is consistent with the results of ecological surveys conducted during the same period, which showed a decline of 6.00%. For the Unnamed Reef in the Great Barrier Reef, the live coral cover decreased from 18.16% to 10.85%, a decline of 7.31%, which is also in line with the ecological survey results showing a decline of 6.80%. From 2020 to 2022, there were the slightest signs of recovery in the Unnamed Reef, while Kure Atoll continued to experience a decrease, but at a slower rate.

Comprehensive Assessment of Typical Coastal Bay Ecosystem Health in China

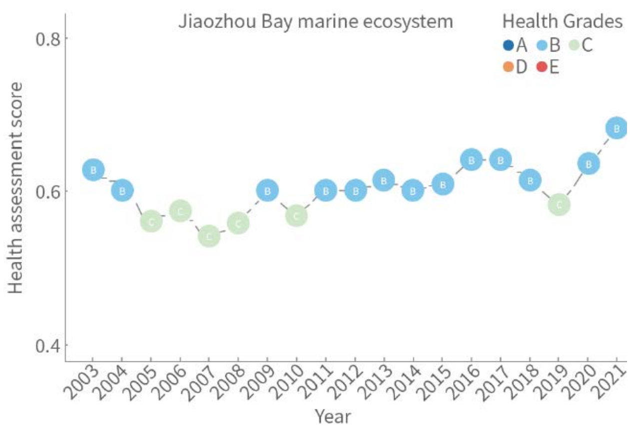
SDG 14.2: By 2020, sustainably manage and protect marine and coastal ecosystems to avoid significant adverse impacts, including by strengthening their resilience, and take action for their restoration in order to achieve healthy and productive oceans

The Jiaozhou Bay is located on the south side of the Shandong Peninsula, within the administrative boundary of Qingdao, Shandong. The bay is densely populated, with developed industry and agriculture. The ecological environment of the bay is influenced by intense human activities such as urbanization, coastal reclamation, land-based material discharge, international shipping, large-scale engineering, and marine aquaculture. It represents a typical temperate coastal bay in China and effectively captures the developmental history of the eastern coastal region. In this case, a report card assessment model for the health of nearshore ecosystems (Logan *et al*., 2019) was constructed, and machine learning techniques were combined to develop an assessment method suitable for multi-scale marine ecological parameters. Long-term observational Big Earth Data were utilized to achieve a comprehensive assessment of the health of the Jiaozhou Bay ecosystem over a long period of time, providing insights for sustainable bay development research.

Since 2010, the health of the Jiaozhou Bay ecosystem has shown an overall improvement and reached its best level in nearly 20 years in 2021. The health grade of the Jiaozhou Bay ecosystem was B in 2021, indicating a good status. There was no significant difference in the health status among different regions of the bay, as all regions were in a B grade of good status (Figure 7-5). From the perspective of long-term changes, the overall health condition of the Jiaozhou Bay ecosystem has been trending positively since 2010. However, there was a fluctuation in 2019 due to outbreaks of jellyfish and Noctiluca. The health assessment score of the bay in 2021 reached its highest level in nearly 20 years (Figure 7-6).



↑ Figure 7-5 Health assessment results of Jiaozhou Bay and various marine ecosystems in 2021



↑ Figure7-6 Jiaozhou Bay marine ecosystem health assessment scores, 2003–2021

The Jiaozhou Bay has achieved a healthy ecosystem and high-quality development of the marine economy through effective land-sea coordination and strengthened nearshore management. In 2021, the marine GDP of Qingdao reached CNY 468.484 billion, ranking first among similar coastal cities in China. While maintaining rapid and high-quality economic growth, the health of the Jiaozhou Bay's marine ecosystem continues to improve, due to the effective environmental governance and protection measures. Comprehensive measures, such as the control of nearshore water pollution and reduction of land-based pollution, have effectively reduced the input of pollutants and lowered the nutrient concentration in the bay. Measures like shoreline management and restoration of bay areas ensure unobstructed flow patterns in the bay's hydrodynamic environment. The stability of benthic shellfish resources and a sound benthic ecosystem guarantee the normal biogeochemical cycles in the bay (Sun *et al*., 2015). The Jiaozhou Bay has implemented multiple concurrent strategies, providing an important foundation for achieving the goal of sustainable development in the bay.

Sustainable Management of Aquaculture

China is one of the most developed countries in marine aquaculture in the world and is the only country where aquaculture production surpasses fishing. The scientific management of aquaculture types, scale, and distribution is of significant importance in promoting harmonious coexistence between human aquaculture activities and the marine environment, preserving biodiversity, and fostering the sustainable development of marine aquaculture. This theme focuses on dynamic monitoring and analysis of China's coastal raft culture to provide insights on sustainable management approaches in marine aquaculture.

Dynamic Remote Sensing Monitoring and Analysis of Raft Culture in China's Coastal Waters

SDG 14.7 By 2030, increase the economic benefits to small island developing States and least developed countries from the sustainable use of marine resources, including through sustainable management of fisheries, aquaculture and tourism

SDG 14

Raft culture is a crucial component of China's marine aquaculture and is continuously evolving in terms of methods and scale. This case study makes full use of multisource satellite remote sensing images from the high-resolution and Sentinel series, and employs a deep-learning-based method for accurately extracting raft culture areas (Zhang *et al*., 2020b; 2022a). The study identifies the aquaculture areas and types through field verification and expert interpretation, thus obtaining multi-temporal data on raft culture to analyze its current status and changes in China.

From 2017 to 2021, the area of marine raft culture in China experienced orderly growth, with distribution trends away from the coastline. In 2017, the monitored area of nearshore raft culture in China was approximately 5,673 km^2, and in 2021, it reached around 5,698 km^2 (Figure 7-7a). Leading provinces in terms of aquaculture area include Shandong, Guangdong, Fujian, Jiangsu, Liaoning, and Hebei (Figure 7-7b). Analyzing the distribution of raft culture at distances of 10 km and 20 km from the coastline, it was found that there was a significant increase in raft culture areas located more than 10 km away from the coastline in 2021.

The structure of raft culture in China's coastal waters is continuously optimizing, and the development of ecologically healthy raft culture models is progressing rapidly. Remote sensing monitoring of nearshore raft culture in China from 2017 to 2021 showed significant changes in the raft culture structure, with more balanced types (Figure 7-7c). Rational planning of different aquaculture types has reduced the potential impact of large-scale monoculture on ecological degradation and biodiversity loss. Moreover, the introduction of new aquaculture technologies and species has further expanded the aquaculture sector, leading to the rapid development of ecologically healthy aquaculture models. Currently, China's nearshore raft culture is in a stage of optimized layout and significantly improved quality.

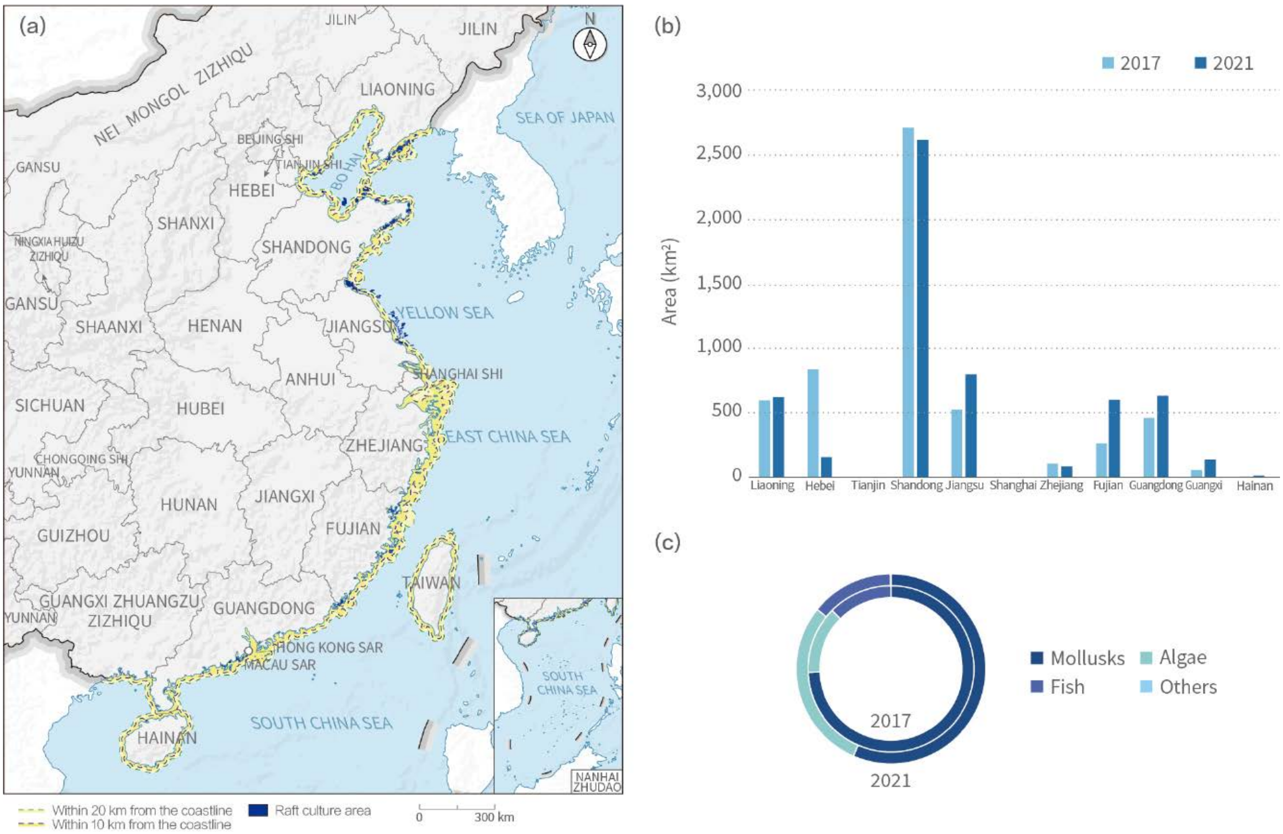


Figure 7-7 Spatial distribution and area statistics of raft culture in China's coastal waters. (a) Spatial distribution of raft culture in 2021; (b) The area of raft culture in different provinces in 2017 and 2021; (c) Changes in raft culture types in 2017 and 2021

Recommendations and Outlook

In this chapter, we conducted case studies on themes such as reducing marine pollution, preserving marine ecosystems, and sustainable management of aquaculture in China's coastal areas. These studies included the distribution and temporal variation of microplastics in China's coastal waters, dynamic monitoring of seagrass meadows, live coral cover in typical coral reefs, comprehensive assessment of typical bay ecosystems, and dynamic remote sensing monitoring and analysis of raft culture. Based on these case studies and the results of the past four years of research using Big Earth Data technology, we summarized China's midterm progress in achieving SDG 14. Despite challenges such as densely populated coastal regions and high demand for marine resources, China has made significant efforts to implement SDG 14 and achieved a series of results, providing a foundation for promoting the achievement of SDGs in the future.

Based on the research in this chapter, we propose the following recommendations:

1. Utilize the opportunity of the 2023 midterm review to reexamine and adjust the relevant indicator system. Currently, there are methods but no data to measure progress on targets such as SDG 14.1, SDG 14.2, SDG 14.3, SDG 14.a, and SDG 14.c, which hinders the understanding of their current status and policy implementation at the UN and by national governments. It is necessary to adjust the existing indicator system, taking into account current focus areas and midterm review process, and obtain more monitoring data for SDG assessment. For example, adding indicators of microplastic pollution and marine radioactivity pollution to SDG 14.1, incorporating indicators for evaluating the recovery of typical marine ecosystems (e.g., mangroves, seagrass meadows, and coral reefs) into SDG 14.2, and

modifying SDG 14.7 to focus on increasing sustainable fishery scale or value in all countries.

2. Further encourage and guide countries to increase support for marine scientific research through the implementation of the Decade of Ocean Science. This can be achieved by increasing investment in marine science and establishing new marine research platforms, encouraging participation from enterprises and the public to enhance the capacity for marine data collection and analysis. Additionally, stronger international cooperation in the field of oceanography will promote the management, openness, and sharing of marine data resources, better supporting the achievement of marine sustainable development goals.

3. Conduct more in-depth and comprehensive scenario analysis on China's achievements and challenges in marine sustainable development, especially in the context of carbon peak and carbon neutrality goals, and global climate change. More research cases will offer scientific evidence for and inform decisions on paths towards healthy and sustainable development in nearshore areas.

In the future, we will continue to improve the sharing and application capabilities of Big Earth Data in the field of marine sustainable development. By establishing data sharing platforms, online computing platforms, and data service platforms, we will facilitate the timely sharing and dissemination of data and knowledge, enhance the level of blue economy development and marine technological innovation, and contribute to the implementation of the UN 2030 agenda.

SDG 15
Life on Land

SDG 15

Background

At the halfway point of the 2030 Agenda, the situation for achieving SDG 15 remains very challenging. The global forest area (SDG 15.1.1) is steadily decreasing (FAO, 2020), with approximately 75% of the land still experiencing degradation (SDG 15.3.1) (IPBES, 2019). While there has been some increase in the proportion of globally important biodiversity sites under protection (SDG 15.1.2, SDG 15.4.1), the Red List Index (RLI) (SDG 15.5.1) continues to decline (UNEP, 2021a). At the current pace, it is difficult to achieve SDG 15 by 2030 (UN, 2022).

However, in the context of a somewhat bleak global outlook for SDG 15, China's progress in achieving SDG 15 appears more positive. In recent years, China has comprehensively carried out ecosystem protection and restoration efforts. Since 2015, forest coverage has increased by 2.36%, and approximately 2.3% of China's land territory has been put under protection under the pilot program for the national park system. China has also achieved continuous reductions in both desertification and land degradation. The continuous decline status in the number of several endangered wildlife species, such as giant pandas, crested ibises, Asian elephants, and Xizang antelopes, has been basically reversed, and their populations are showing signs of recovery.

As 2023 marks the midpoint review of SDGs, assessing progress on SDG 15 is crucial for understanding achievements, identifying gaps, and implementing effective interventions. There is widespread recognition among UN agencies of the importance of leveraging the advantages of big data to fill data gaps and conduct continuous geospatial assessments of SDG progress. The relevant data has become essential supplements to national SDG statistical data. As data availability improves and technological methods develop, eight out of the 14 indicators covered by SDG 15 now have both methods and data available. However, the acquisition methods for these indicators are mainly statistical and lack scalability across different scales (global, regional, national, and local) (UNEP, 2021a), making it difficult for many developing countries with limited capabilities to conduct progress assessments.

Over the past four years, this report has focused on a series of innovations and practices in Big Earth Data-enabled monitoring methods for indicators in forest conservation and restoration, biodiversity protection, land degradation and restoration, mountain ecosystem conservation, and invasive alien species. It has also explored preliminary pathways for improvement in the future. This year's report will build upon the review of various indicator assessment results and their supportive role for the midterm review and continue to utilize cutting-edge technologies such as Earth observation and artificial intelligence to conduct global and China-scale assessments of SDG 15 progress, aiming to provide support for the midterm evaluation of SDG 15 and its realization in the future.

Midterm Progress

Based on the 2019–2022 reports and the results of this chapter's research, the midterm progress was assessed of SDG 15 related to global/Chinese forest cover (SDG 15.1.1), biodiversity protection (SDG 15.1.2, SDG 15.4.1), sustainable forest management (SDG 15.2.1), land degradation (SDG 15.3.1), Mountain Green Cover Index (SDG 15.4.2), Red List Index (SDG 15.5.1), and prevention and control of invasive alien species (SDG 15.8.1). The Big Earth Data evaluation results indicate that the global trend of land degradation is improving, and the Mountain Green Cover Index remains relatively stable. China has achieved three indicators—SDG 15.1.1, SDG 15.3.1, and SDG 15.4.2, and other indicators have shown positive. The specific progress is as follows:

1. Regarding forest protection and restoration (SDG 15.1.1), this report's research shows that China's forest area is significantly increasing, and afforestation efforts have been effective. In terms of forest biomass (SDG 15.2.1), China's forest Aboveground Biomass (AGB) has shown an overall increasing trend from 2015 to 2021, with a more significant increase in the southern region.

2. In the prevention and control of land degradation (SDG 15.3.1), the 2020 report and this report's research show that the global trend of SDG 15.3.1 is positive, but there are significant spatial differences among different countries. China has achieved Land Degradation Neutrality (LDN) ahead of schedule and continues to improve. During the

monitoring period (2015–2020), the average annual net restoration rate of land increased by nearly 5% compared to the baseline period (2000–2015). Dust storms on the Mongolian Plateau are mostly initiated in western Mongolia, and the frequency and intensity of dust storms are closely related to natural and human activities.

3. In mountain ecosystem protection, the 2021 and 2022 reports' research shows that concerning the coverage of protected areas of important sites for mountain biodiversity (SDG 15.4.1), as of 2020, two-thirds of China's protected wild plant and animal species in mountainous regions, and 86.9% of priority protected natural ecosystems were under the coverage of nature reserves, providing important safeguards for mountain biodiversity protection. As for the Mountain Green Cover Index (SDG 15.4.2), from 2015 to 2020, it remained relatively stable at the global and Chinese scales. In 2020, the Mountain Green Cover Index averaged about 80% globally and about 82% in China.

4. Regarding species protection, this report's research shows that from 2013 to 2020, China's Red List Index for higher plants (SDG 15.5.1) slightly increased, and the effectiveness of threatened species protection remained stable and improved slightly. Harvesting, agriculture and aquaculture are the main factors endangering higher plants.

5. In the prevention and control of invasive alien species (SDG 15.8.1), the 2022 report and this report's research show that from 2012 to 2022, the distribution of China's six typical agricultural invasive pests maintained relatively stable. Under future climate scenarios, it is necessary to strengthen early warning and prediction of the new distribution areas and migration directions of invasive pests to better control invasive alien species.

SDG 15 Life on Land: Global/China Midterm Progress

Global forest covered area shows a declining trend, with a net decrease of **29 million** hectares from 2019 to 2021[1].

SDG 15.1.1

From 2015 to 2021, China's forest aboveground biomass showed an overall **increasing trend**[1].

SDG 15.2.1

Global trend of land degradation is **improving**, with significant regional differences[2].

SDG 15.3.1

China has achieved land degradation neutrality ahead of schedule. During the monitoring period(2015–2020), the average annual net restoration rate of land increased by nearly **5%** compared to the baseline period(2000–2015)[1,2].

SDG 15.3.1

By 2020, **2/3** of China's key protected wild species and **86.9%** of priority-protected natural ecosystems in mountain areas were covered by natural protected areas[3].

SDG 15.4.1

The Mountain Green Cover Index remains relatively stable both globally and in China. It averaged approximately **80%** globally and about **82%** in China in 2020[4].

SDG 15.4.1

China's Red List Index for higher plants **slightly increased** from 0.98792 in 2013 to 0.98797 in 2020[1].

SDG 15.5.1

From 2012 to 2022, the distribution of China's six typical agricultural invasive pests remained **relatively stable**[1].

SDG 15.8.1

Major invasive alien species including smooth cordgrass (*Spartina alterniflora*), ragweed (*Ambrosia artemisiifolia*) and potato beetle (*Leptinotarsa decemlineata*) have been brought under **effective control**[1,3].

SDG 15.8.1

Notes:

1.Big Earth Data in Support of the Sustainable Development Goals (2023); 2.Big Earth Data in Support of the Sustainable Development Goals (2020); 3.Big Earth Data in Support of the Sustainable Development Goals (2022); 4.Big Earth Data in Support of the Sustainable Development Goals (2021).

Thematic Studies

Forest Conservation and Restoration

Forests are one of the most important carbon reservoirs in terrestrial ecosystems, playing a crucial role in preventing soil erosion, mitigating climate change, and maintaining biodiversity. Earth observation technologies have been widely used in forest type mapping and vegetation cover estimation. Currently, there are several global-scale forest classification and cover products. However, these products suffer from issues such as lack of fine classification, spatial discontinuity, and high uncertainty. To address these challenges, we have fully explored the potential of Big Earth Data to monitor forest cover and oil palm distribution. Additionally, we have assessed the dynamic changes in aboveground biomass of Chinese forests, aiming to provide data and method for sustainable forest management.

Dynamic Change in Forest Cover and Aboveground Biomass

SDG 15.1: By 2020, ensure the conservation, restoration and sustainable use of terrestrial and inland freshwater ecosystems and their services, in particular forests, wetlands, mountains and drylands, in line with obligations under international agreements

By using advanced technologies such as machine learning and big data analysis, we have produced global forest cover products based on long time-series multisource satellite remote sensing data. Globally, 43 forest regions were established, and high-quality forest sample points were collected to build a rapid production process and scheme for global forest cover products using machine learning and big data analysis techniques, achieving rapid production of global time-series forest cover products (Zhang *et al.*, 2020c). In China, the country was divided into 17 spatially coherent forest regions with consistent forest types. By integrating biomass data of forest sample obtained from ground surveys, Landsat satellite data, forest height products, DEM, terrain, and other parameters, we used the random forest algorithm to establish a forest aboveground biomass inversion model for each region and forest type, generating a national 30 m

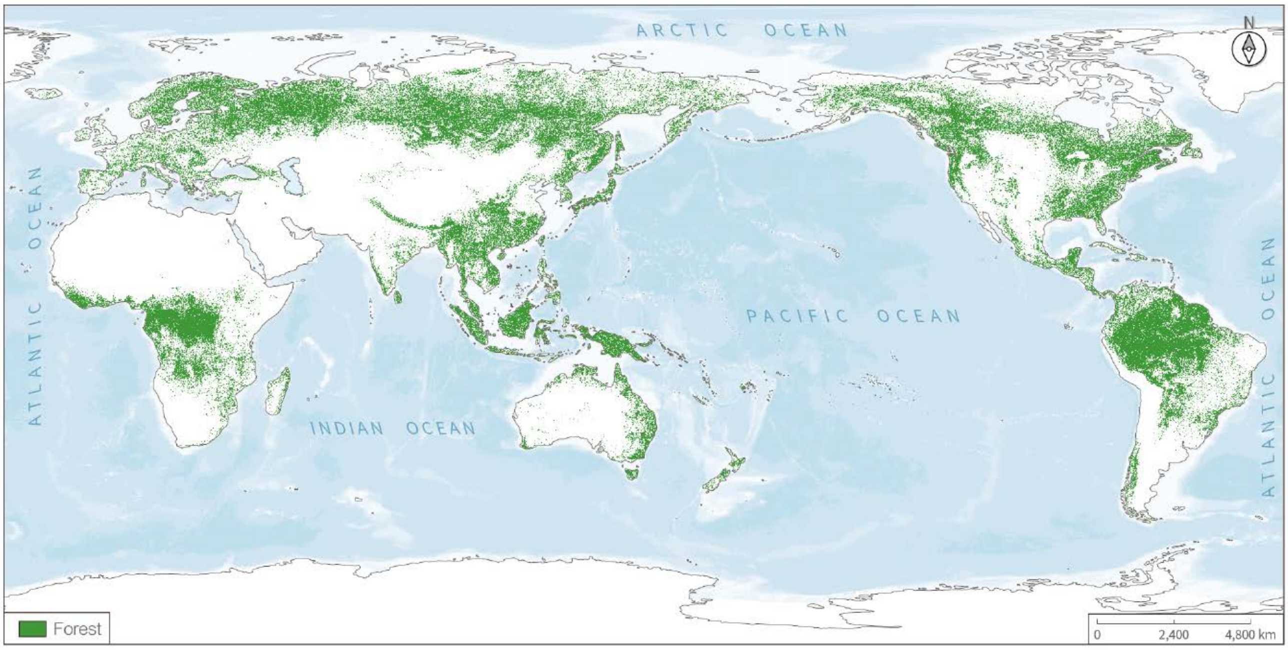
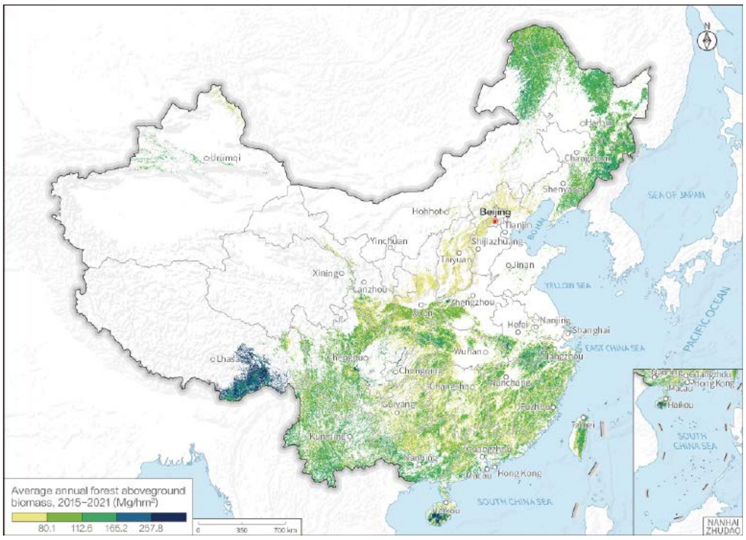


Figure 8-1 Global forest distribution in 2021

resolution forest aboveground biomass product.

Global forest cover area is showing a declining trend, with a net decrease of 29 million hectares between 2019 and 2021. The changes in forest area demonstrate significant regional differences, with forest cover in Sub-Saharan Africa, Southeast Asia, and South America experiencing substantial reductions, while showing significant increases in Europe and East Asia. China's forest cover has gradually increased, exhibiting the characteristics by more in the east and southwest and less in the northwest (Figure 8-1).

The overall trend of forest biomass per unit area has improved in China. From 2015 to 2021, the trend of forest biomass in China was generally positive. There are significant differences in the change of forest aboveground biomass among various vegetation zones in China, with the southern forests showing a higher increase rate compared to the northern regions (Figure 8-2).



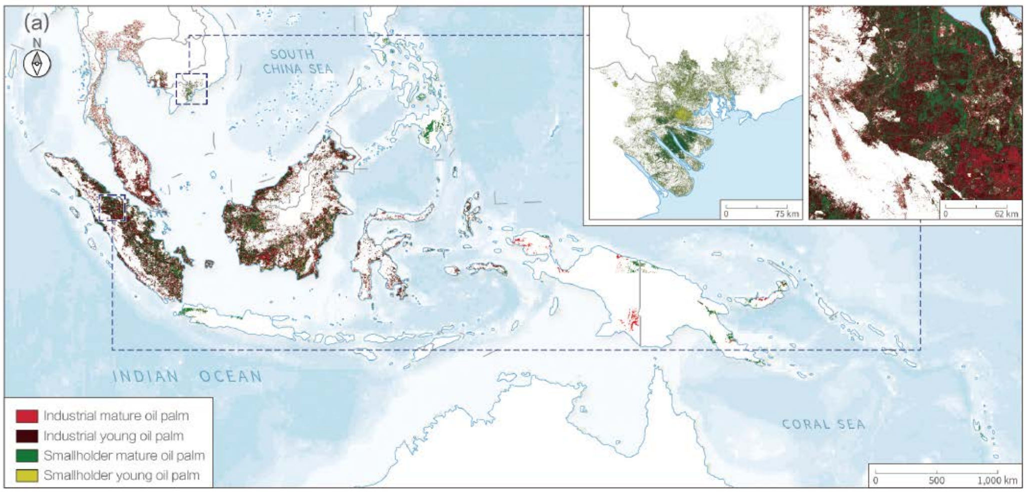
↑ Figure 8-2 Average annual forest aboveground biomass distribution in Chinese forests, 2015–2021

Note: The vegetation division adopts the classification method from Vegetation Map of the People's Republic of China (1:1,000,000).

Global Spatial Distribution of Oil Palm

SDG 15.2: By 2020, promote the implementation of sustainable management of all types of forests, halt deforestation, restore degraded forests and substantially increase afforestation and reforestation globally

Oil palm is the most productive oil-producing plant in the world, and palm oil extracted from oil palm fruits is the second-largest edible vegetable oil globally. Accurate knowledge of the distribution of oil palm plantations is essential for sustainable forest management. In this study, a pixel-oriented classification approach at each grid-based small region (100 km×100 km) was used to conduct global-scale mapping of oil palm subclasses. The main process includes selecting suitable areas for global oil palm plantations based on the required terrain, soil, climate, and socio-ecological standards. A sample library was established, and remote sensing images were classified using machine learning methods to obtain the spatial distribution patterns of different oil palm subclasses and subsequently the global mapping of oil palm distribution was completed.



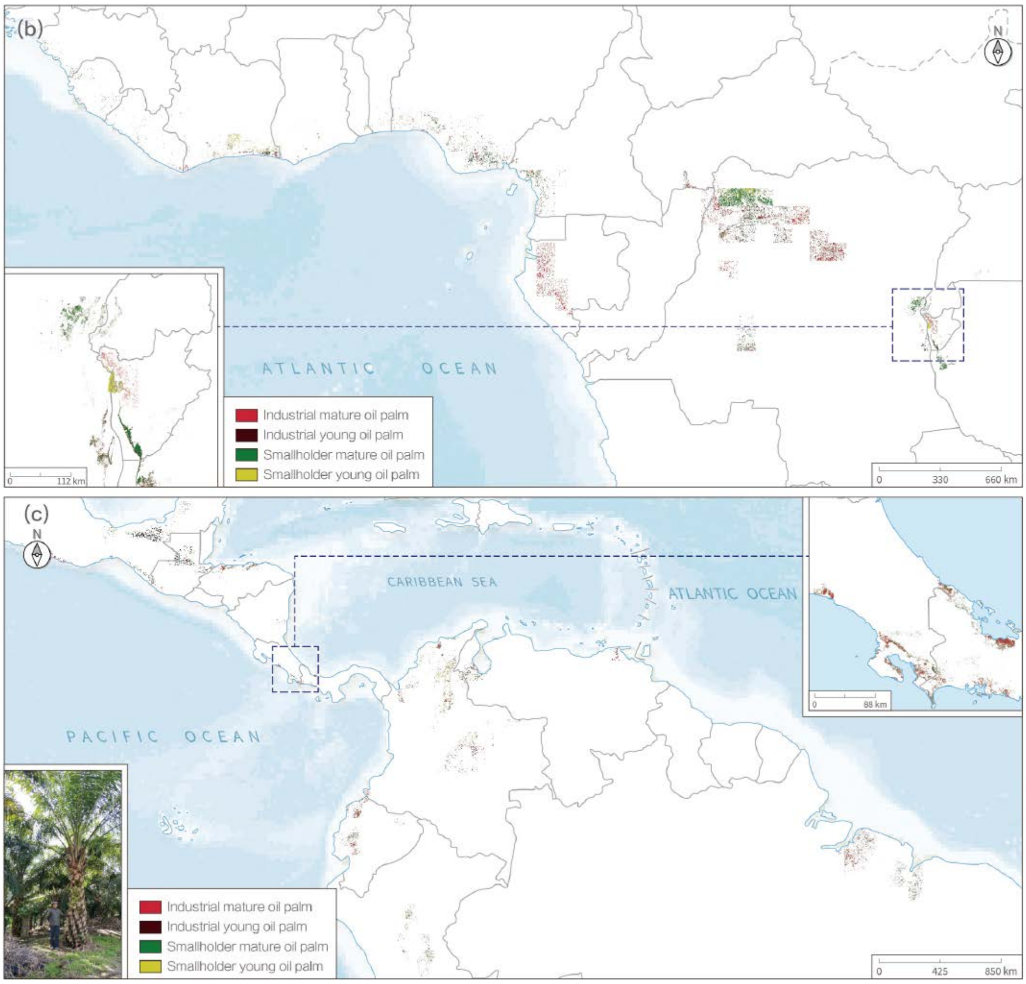


Figure 8-3 Spatial distribution of oil palm subclasses. (a) Southeast Asia and the Pacific Region; (b) West and Central African Region; (c) Central and South American Region

In 2020, the total global oil palm plantation area was 72.67 million hectares. Southeast Asia had the largest plantation area of 59.70 million hectares, accounting for 82.15% of the total; Central and South America had the second-largest plantation area of 6.35 million hectares, accounting for 8.74%; West and Central Africa had a plantation area of 5.63 million hectares, accounting for 7.75%. Ten countries, including Indonesia, Malaysia, Cambodia, Nigeria, and Colombia, had all four oil palm subclasses (Figure 8-3).

There were significant differences in the distribution area and proportion of oil palm subclasses in different regions worldwide (Table 8-1). The proportions of the four subclasses—industrial mature, industrial young, smallholder mature, and smallholder young oil palm plantations were 31%, 17%, 35%, and 17% of the total oil palm plantation area, respectively. Southeast Asia and the Pacific region had the highest proportions of the four oil palm subclasses, accounting for 84.00%, 95.60%, 72.30%, and 86.30%, respectively. In West and Central Africa and Central and South America, industrial mature and smallholder mature oil palm plantations were the main types, with a smaller proportion of young oil palm plantations.

Table 8-1 Oil Palm Subclass Plantation Areas (Million hectares) in Different Regions

Subclass	Southeast Asia & Pacific	South Asia	Central & West Africa	Central & South America
Industrial mature oil palm	18.66	0.01	1.77	1.77
Industrial young oil palm	11.64		0.07	0.46
Smallholder mature oil palm	18.94	0.98	3.04	3.22
Smallholder young oil palm	10.46		0.75	0.90

Land Degradation Neutrality

Land degradation is a global challenge, and the *Global Land Outlook 2* released in 2022 pointed out that "20%~40% of the world's total land area is experiencing degradation, directly impacting nearly half of the global population" (UNCCD, 2022). Combating desertification and land degradation is a core element of SDG 15.3, and achieving LDN by 2030 has been widely accepted and recognized by the international community. Currently, monitoring and attribution of land degradation and dust storms still face significant challenges, particularly in developing countries. To address this, we have fully leveraged the advantages of Big Earth Data to assess the dynamics of LDN in China. We have also analyzed the dynamics and drivers of dust storms in the Mongolian Plateau and proposed response strategies, aiming to provide new data and methods to achieve the goal of LDN.

Dynamic Changes Towards LDN in China

SDG 15.3: By 2030, combat desertification, restore degraded land and soil, including land affected by desertification, drought and floods, and strive to achieve a land degradation-neutral world

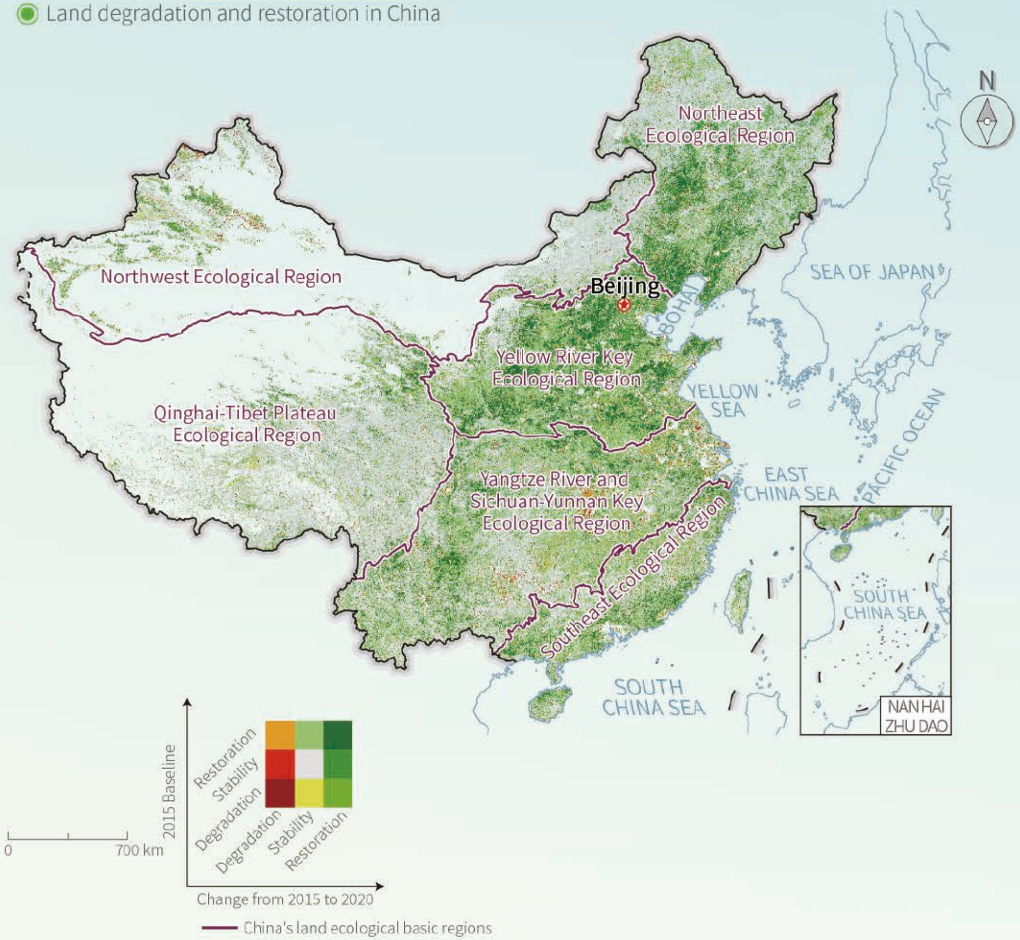
The definition of land degradation has long been a subject of controversy, mainly due to differences in the understanding of various degradation processes, causes, characteristics, and impacts. This has led to significant differences in the assessment results of land degradation, severely affecting the scientific understanding and accurate assessment of the global/regional land degradation situation by the international community. Consequently, it has hindered practical actions and effective prevention and control efforts. In this study, we referred the recommended method of Good Practice Guidance (GPG) for SDG 15.3.1 of the United Nations Convention to Combat Desertification (UNCCD), we conducted a dynamic evaluation for the period 2015 to 2020 using three consistent sub-indicators: land cover, land productivity, and soil organic carbon. Subsequently, by comparing the dynamic changes in land degradation and restoration between the baseline period (2000 to 2015) and the monitoring period (2015 to 2020), we analyzed the dynamic changes of LDN in China.

The results show that the net restoration rate of land in China significantly increased from 2015 to 2020, indicating a continuous improvement towards achieving LDN. During the monitoring period (2015–2020), the average annual net restoration rate of land increased by nearly 5% compared to the baseline period (2000–2015), as illustrated in Figure 8-4. From the perspective of Big Earth Data, the dynamic trends of China's progress towards LDN align with the conclusions in the *2022 Special Data Report* submitted by the National Forestry and Grassland Administration (NFGA) to UNCCD, which pointed out that during the reporting period of 2016–2019, there was a notable reduction in the areas of land degradation in China, as well as a significant positive shift in land productivity within regions prone to desertification.

During the period from 2015 to 2020, the area of land restoration in China significantly exceeded that of degradation, with significant variations observed across different regions. According to the statistics based on China's terrestrial ecological regions, the Yellow River key ecological region contributed the highest proportion, nearly one-third of China's net land restoration; the Yangtze River and Sichuan-Yunnan key ecological region, and the Southeast ecological region, were severely affected by drought since 2019, leading to a significant decline in the productivity of arable land and forests; the Northwest ecological region exhibited a relatively high proportion of land degradation, suggesting that it should be a focal area of attention in China's upcoming "Three-North" reforestation initiative.

Figure 8-4

Land degradation and restoration in China



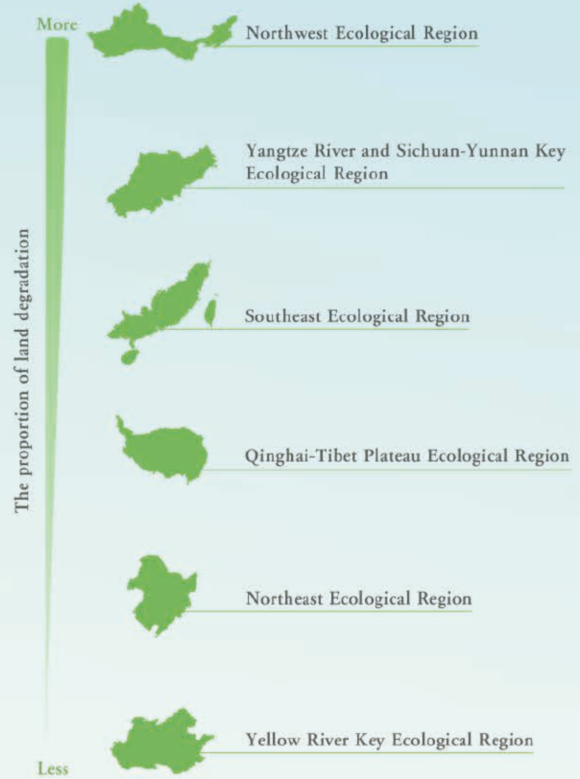
During the monitoring period (2015–2020), the average annual net restoration rate of land increased by nearly 5% compared to the baseline period (2000–2015)

5%

The Yellow River key ecological region contributed the highest proportion, nearly one-third of China's net land restoration

1/3

During the period from 2015 to 2020, the area of land restoration in China significantly exceeded that of degradation, with significant variations observed across different regions.



Dynamic Change in Sand and Dust Storms in the Mongolian Plateau and Response Strategies

SDG 15.3: By 2030, combat desertification, restore degraded land and soil, including land affected by desertification, drought and floods, and strive to achieve a land degradation-neutral world

The Mongolian Plateau is one of the major sources of sand and dust storms (SDS) in Asia, with the Gobi Desert areas in Mongolia and the desert areas in western Inner Mongolia in China having a close relationship with the frequent SDS events in recent years. SDS is a kind of dust weather, specifically refers to the strong wind rolled up a large amount of dust from the ground to make the horizontal visibility less than 1 km, with sudden and short duration characteristics of small probability and great harm. The whole territory of Mongolia and the Inner Mongolia Autonomous Region of China are taken as the research area. Using MODIS L1B data as the source, a Dust Storm Detection Index (DSDI) model was constructed to obtain a data set of SDS distribution in the Mongolian Plateau during the spring season for 22 years (2000–2021). By analyzing the frequency, extent, intensity, and spatial distribution of SDS from both temporal and spatial perspectives, the basic characteristics of SDS in the Mongolian Plateau for the 22-year period were summarized. Furthermore, utilizing Landsat 8 data for the six years of 2000, 2005, 2010, 2015, 2020, and 2021, in combination with relevant models, a data set of sand distribution in the Mongolian Plateau from 2000 to 2021 was derived, along with the underlying land cover pattern and changes. Finally, considering the underlying land cover conditions, meteorological data, and SDS control measures taken by China and Mongolia, the causes of SDS occurrences in the Mongolian Plateau were analyzed, and relevant response strategies were proposed based on the research findings.

The spring SDS in the Mongolian Plateau from 2000 to 2021 had a clear spatial pattern and transmission path. Their overall spatial distribution shows a trend of more occurrences in the south than in the north, and more in the west than in the east, with a gradual decrease from west to east and from south to north (Figure 8-5). The main area impacted by SDS is the border region between China and Mongolia, particularly the southern part, which is most affected. The SDS path often originates from the western regions of Mongolia, such as Bayanhongor and Ovorhangay

No.	Name	No.	Name
1	Bayanhongor	11	Hangjin Banner
2	Ovorhangay	12	Urad Middle Banner
3	Omndgovi	13	Urad Front Banner
4	Dundgovi	14	Dalat Banner
5	Dornogovi	15	Darhan Muminggan Joint Banner
6	Ejina Banner	16	Siziwang Banner
7	Alxa Right Banner	17	Erenhot
8	Alxa Left Banner	18	Sunid Right Banner
9	Urad Rear Banner	19	Sunid Left Banner
10	Otok Banner	20	Abag Banner

↑ Figure 8-5 Spatial distribution of spring sandstorm frequency on the Mongolian Plateau, 2000–2021

SDG 15

provinces, and progresses by gathering dust sources from the central, eastern, and southern Gobi regions of Mongolia before directly impacting the border areas between China and Mongolia and impacting Inner Mongolia in China. Occasionally, under the influence of cyclones, SDS may reach the northeastern region of Inner Mongolia in China.

The frequency and extent of SDS in the Mongolian Plateau show interannual variations, and there is a partial association between their occurrence and natural and human activities. From 2000 to 2021, a total of 80 typical spring SDS events in the Mongolian Plateau were observed through remote sensing. The high occurrence period is from March to May. During the years from 2000 to 2010, the number of spring SDS occurrences in the Mongolian Plateau was relatively high, reaching 52 times (accounting for 85%). However, the SDS that occurred in the spring of 2021 brought significantly increased harm, reflecting the uncertainty against the background of climate change and the rise of extreme weather events. Geographical factor analysis revealed that bare land increased by 1.3% from 2000 to 2010, and decreased by 1.9% from 2010 to 2015, positively correlating with the SDS frequency. The correlation coefficient between precipitation and SDS extent was -0.73, showing a negative correlation. In the future, China-Mongolia cross-border desertification control and ecological projects should be strengthened to reduce the adverse effects of SDS.

Red List Index

The Red List Index is the most effective indicator for assessing the changing trends in the conservation status of species, and it is widely used at both national and global scales. China is a signatory to the Convention on Biological Diversity (CBD) and has actively promoted the signing of the Kunming-Montreal Global Biodiversity Framework, fulfilling its responsibilities as a mega-diverse country through concrete actions. Research on the trends in biodiversity change can evaluate China's contributions to global biodiversity conservation.

China's Red List Index for Higher Plants

SDG 15.5.1: Red List Index

The International Union for Conservation of Nature Red List of Threatened Species provides one of the core methods in biodiversity conservation. The RLI reflects the changes in the degree of species endangerment and the effectiveness of biodiversity conservation efforts. Previous calculations of the RLI for higher plants in China were limited to a small number of species, only partially reflecting the changes in the threatened status of plants. In this chapter, the RLI for higher plants is primarily based on the *Red List of China's Higher Plants* published by the Ministry of Ecology and Environment (formerly the Ministry of Environmental Protection, MEP) and the Chinese Academy of Sciences (MEP & CAS, 2013), its 2020 edition (MEE & CAS, 2023), and *Seed Plants of China: Checklist, Uses and Conservation Status* (Qin, 2020), and data from the Chinese Virtual Herbarium and IUCN. Following the methods of Butchart *et al.* (2004) and Butchart *et al.* (2007), a total of 32,054 species of higher plants assessed in both years were selected, and then extinct species from 2013 and species with insufficient data were excluded. The RLI was calculated using the relative weighting method, with the weight values assigned as shown in Table 8-2.

Table 8-2 Relative Weighting Method for Calculating Red List Index

Level	Relative Weight
Extinct (EX)	1
Extinct in the Wild (EW)	1
Regionally Extinct (RE)	1
Critically Endangered (CR)	0.5
Endangered (EN)	0.05
Vulnerable (VU)	0.005
Near Threatened (NT)	0.0005
Least Concern (LC)	0

The RLI for higher plants in China was 0.98792 in 2013 and slightly increased to 0.98797 in 2020. The level of threat decreased for threatened species than it increased in China, reflecting an overall improvement in species conservation status. For instance, among the threatened species in 2013, 112 critically endangered species, 174 endangered species, and 184 vulnerable species had their threat levels reduced in the 2020 assessment, while only 86 threatened species experienced an increase in the threat level. This positive trend is attributed to China's implementation of various biodiversity conservation measures and projects, such as afforestation, grassland restoration, and ecological restoration initiatives, contributing significantly to global biodiversity conservation efforts.

Threatened species in China are primarily found in low-altitude areas, and major threats arise from activities such as harvesting and collecting, agriculture, and aquaculture. Approximately half of the threatened species occur at elevations below 1,000 m, around 80% at elevations below 2,000 m, and only about 15% at elevations above 3,000 m (Figure 8-6). In 2013, major threats to China's threatened species were attributed to agriculture and aquaculture, and harvesting and collecting, accounting for more than half of the recorded threats (29.4% and 25.7%, respectively), followed by biological invasion (10.7%). In the 2020 assessment, the impact of multiple threats was evident, with harvesting and collecting, human disturbance, agriculture and aquaculture, and changes to natural systems being the main contributing factors, accounting for 60.2% of the recorded threats.

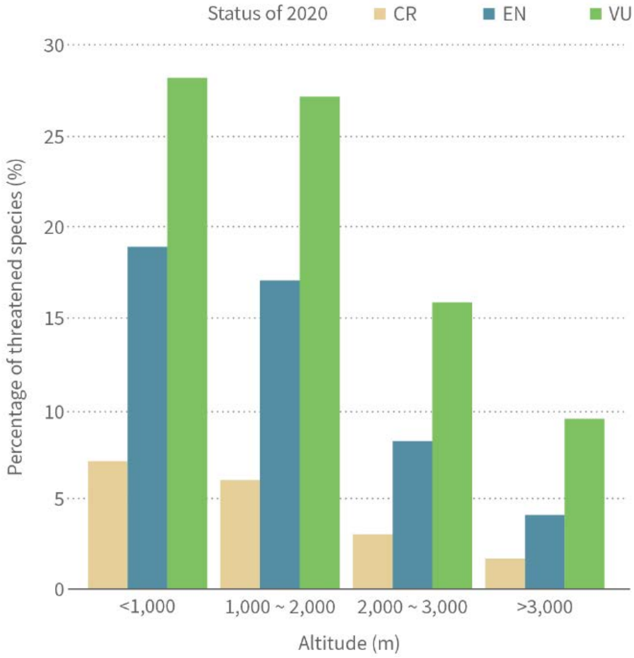


Figure 8-6 Altitudinal distributions of threatened species

Note: It shows the percentages of threatened species at a certain level occurring in each altitude range of the total number of threatened species.

Invasive Alien Species

Invasive alien species are widely recognized as a major factor contributing to the loss of biodiversity. China faces the threat of invasive alien species, with some of these species having invaded various ecosystems such as forests, farmlands, rivers, wetlands, and grasslands. China places great emphasis on the management of invasive alien species and has incorporated it into Biosecurity Law of the People's Republic of China. However, there is a lack of effective data and methods regarding the spatial distribution and dynamics of invasive alien species. In addressing this gap, we have conducted predictions and assessments of the distribution of six key agricultural invasive pests in China, aiming to provide support in addressing the aforementioned challenges.

Prediction and Assessment of Distribution of Key Agricultural Invasive Pests

SDG 15.8: By 2020, introduce measures to prevent the introduction and significantly reduce the impact of invasive alien species on land and water ecosystems and control or eradicate the priority species

The impact of agricultural invasive pests on ecology, society and economy is closely related to multiple SDGs and is a significant factor contributing to issues such as hunger and health crises. In this case, we first analyzed the distribution data of six agricultural invasive pests and dynamically simulated their expansion trends. Based on occurrence data and climatic environmental data, ecological niche models were employed to predict the potential distribution areas under current and future scenarios and were overlaid with relevant crop planting areas. This section proposes three indicators to measure the control effectiveness, potential harm, and future expansion trends of invasive pests: $R1$, the proportion of invaded area to the potential invaded distribution area; $R2$, the proportion of invaded planting area to the potential invaded planting area; $R3$, the proportion of potential suitable distribution area increment in future climate scenarios compared to present scenarios.

China's six major agricultural invasive pests have been effectively controlled. The number of counties invaded by Colorado Potato Beetle (*Leptinotarsa decemlineata*), Bean Weevils (*Acanthoscelides obtectus*), Grape Phylloxera (*Daktulosphaira vitifolia*) and Cowpea Weevil (*Callosobruchus maculatus*) remains relatively stable. The number of counties invaded by Solenopsis Mealybug (*Phenacoccus solenopsis*) and Japanese Orange Fly (*Bactrocera tsuneonis*) has decreased. The invasion of all six pests is controlled within a relatively small area ($R1 < 0.1$). Among them, the invasion area of potato beetle accounts for a small proportion of the potato planting area ($R2 = 0.04$), and it has not entered the large potential habitat in the central and eastern regions, showing effective control and providing important protection for China's potato planting industry (Figure 8-7).

Under future climate scenarios, it is necessary to strengthen early warning and prediction of new distribution areas and the transitory trajectories of invasive pests. A prevailing pattern is observed wherein these pests exhibit a tendency to migrate towards higher latitudes and altitudes, posing greater risks to areas originally unsuitable to their habitation. Therefore, further assessment and monitoring of current and future potential distribution areas are needed, enabling timely detection and control measures.

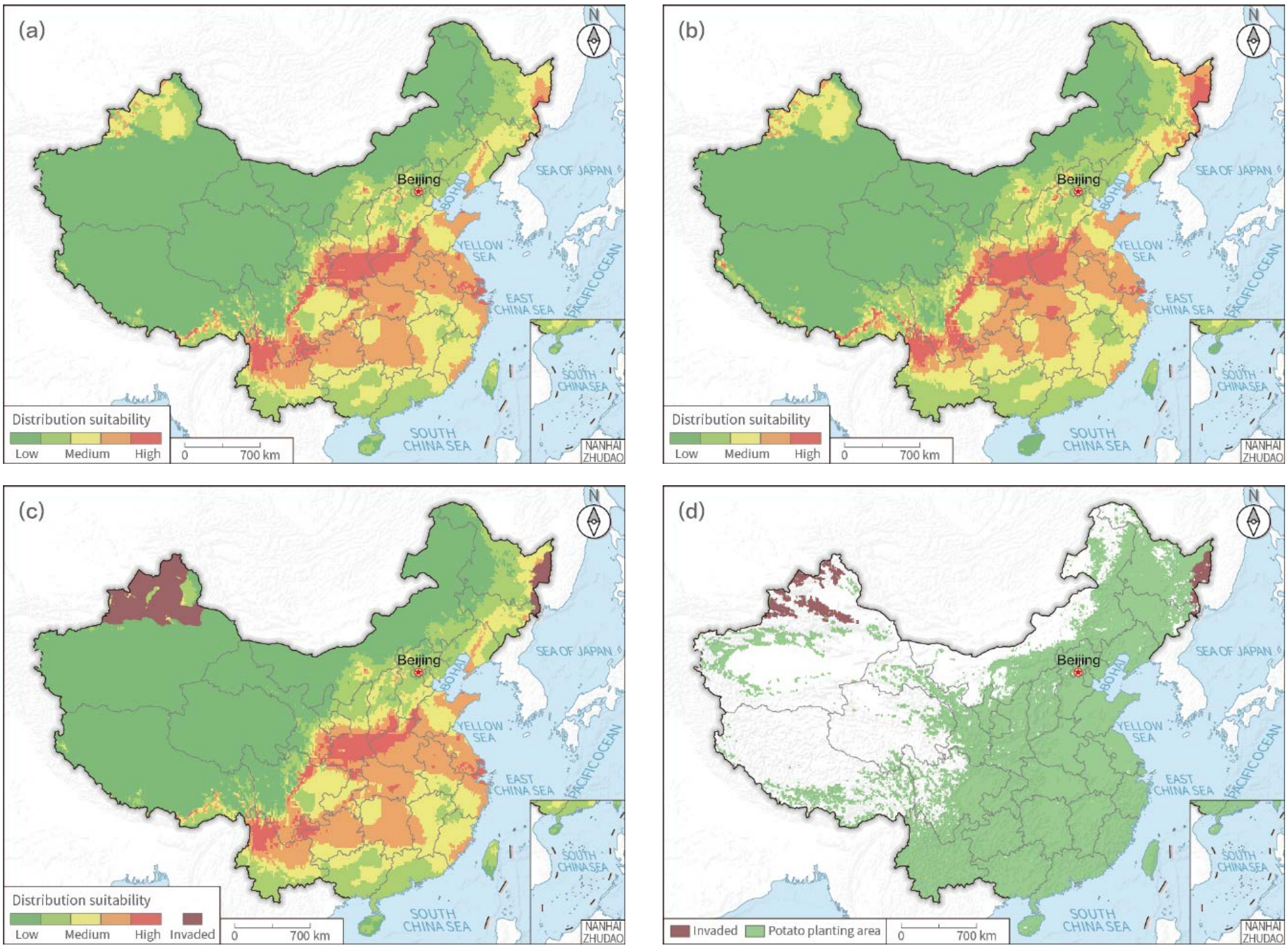


Figure 8-7 Prediction and evaluation of potential distribution and control effect of potato beetle. (a) Current potential distribution area; (b) Future potential distribution area; (c) Overlay analysis of invasive area and potential distribution area; (d) Overlay analysis of invasive area and potato planting area

SDG 15

Comprehensive Demonstration of Ecosystem Restoration

In order to halt ecosystem degradation and promote the achievement of SDG 15 on a global scale, the United Nations launched in 2021 the Decade on Ecosystem Restoration (2021–2030). As part of this initiative, the first batch of flagships programs was selected worldwide, showcasing the best and most promising cases of large-scale and long-term ecosystem restoration at the national or regional level. China's Integrated Protection and Restoration of Mountains, Waters, Forests, Farmlands, Lakes, and Grasses, and Sand Control (known as the Shan-Shui Initiative), which takes all ecosystems as a "community of life", has restored millions of hectares of landscapes in China. It has been recognized as one of the United Nations' inaugural top ten World Restoration Flagships. Examining how well typical ecosystem restoration projects work using Big Earth Data and learning from their successes is of value to the United Nations' Decade on Ecosystem Restoration.

Ecological Restoration Achievements and Experience of Saihanba Mechanized Forest Farm in Hebei

SDG 15: Protect, restore and promote sustainable use of terrestrial ecosystems, sustainably manage forests, combat desertification, and halt and reverse land degradation and halt biodiversity loss

Saihanba Mechanized Forest Farm in Hebei exemplifies China's Shan-Shui Initiative. It has been recognized with the Champions of the Earth award, the UN's highest environmental honor, as well as the Land for Life Award from the UN Convention to Combat Desertification. This case study used the Big Earth Data methodology to assess the ecological restoration outcomes of Saihanba Mechanized Forest Farm. The results demonstrate positive progress towards SDG 15 and other objectives: From 1962 to 2021, the forest area of Saihanba increased from 240,000 mu (16×10^3 hm^2) to 1.151 million mu (76.7×10^3 hm^2) (Figure 8-8), forest coverage rose from 11.4% to 82%, and forest volume grew from 330,000 m^3 to 10.368 million m^3. Between 2000 and 2022, the net increase in land productivity in the Farm reached 53.05%, with an average annual net increase of 2.31%. Notably, the forest at Saihanba shows significant carbon sequestration benefits, with a net increase rate of 2,576 t/a in forest ecosystem carbon sink (net ecosystem productivity) from 2000 to 2020.

Guidance on the idea of ecological civilization and pioneering technological innovation are the key factors behind the success of Saihanba Mechanized Forest Farm. The developmental journey of Saihanba Forest Farm exemplifies the effective implementation of ecological civilization construction. It serves as proof that with scientific planning, natural ecosystems can undergo restoration and transformation, turning barren sandy areas into lush landscapes. By adhering to green development, ecological advantages can be translated into economic strengths, turning lucid waters and lush mountains into invaluable assets. To overcome the challenges posed by extreme cold and arid conditions, the

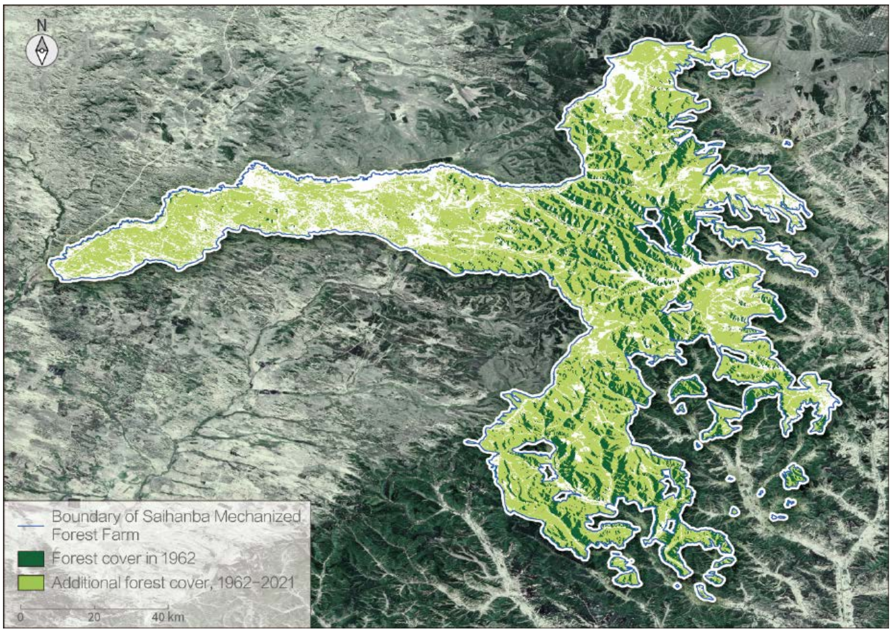


Figure 8-8 Forest cover change in Saihanba Forest Farm, 1962–2021

Farm has embraced a strategy of sustainable management for artificial forests, focusing primarily on *Larix gmelinii* var. *principis-rupprechtii* and *Pinus sylvistris* var. *mongolica*. The Farm has developed techniques for successful afforestation under adverse conditions, the renovation of degraded secondary forests, and an integrated approach to forest ecosystem management. These efforts have contributed to enhanced seedling survival rates, increased productivity per unit area, and improved forest structure. The Farm has also generated ecological and economic value.

Recommendations and Outlook

In this chapter, we focused on themes encompassing forest conservation and restoration, land degradation neutrality, the Red List Index, invasive alien species, and comprehensive ecosystem restoration demonstrations. Our studies delved into topics including forest cover and aboveground biomass dynamics, global oil palm spatial distribution, dynamic trends of land degradation in China, sand and dust storm dynamics and mitigation strategies in the Mongolian Plateau, assessment of China's Red List Index for higher plants, prediction and evaluation of significant agricultural invasive pests, and the ecological restoration achievements and experience of Saihanba Mechanized Forest Farm in Hebei. Drawing on the findings of this chapter's research and combining them with the accumulated knowledge from the past four years of case studies, we summarized the global and Chinese midterm progress towards SDG 15. Since the inception of the SDGs in 2015, positive trends have been observed, including global improvement in land degradation, increasing forest cover and biomass in China, steady enhancement in sustainable forest management practices, continuous expansion of natural protected areas covering a substantial portion of priority species in mountainous regions, and notable achievements in safeguarding threatened species and controlling invasive alien species.

Based on the research in this chapter, we propose the following recommendations:

1. Forest conservation and ecosystem restoration: It is essential to intensify precise monitoring of forest planting and logging through Big Earth Data, along with systematic biodiversity monitoring, to better achieve the goals of forest conservation and restoration. In the pursuit of LDN, we advocate for the priority planning of degraded land restoration, and evaluation and simulation of ecological restoration benefit, leveraging the power of Big Earth Data, to provide robust scientific frameworks for the management of land degradation.

2. Biodiversity conservation: Future efforts should strengthen the utilization of Big Earth Data for prioritization and gap analysis in biodiversity conservation, providing support for balanced utilization and protection, and targeted development of natural protected areas. Enhanced integrated research is needed to address multiple targets, such as mountain biodiversity conservation and sustainable resource development, facilitating the achievement of sustainable mountain development.

3. Invasive alien species control: We recommend consolidating and disseminating successful techniques for invasive alien species control. For species undergoing rapid expansion, increased funding and technological investments are called for to effectively prevent their further spread.

Looking ahead, it is imperative to maximize the value of Big Earth Data to formulate a quantifiable indicator framework specifically tailored to SDG 15, enabling more accurate progress assessment. Additionally, efforts should be made to develop and share high spatiotemporal resolution global remote sensing products for key variables, conduct scientific research on ecosystem and biodiversity conservation in the context of multi-objective coupling, develop tools for decision-making on SDGs implementation, build capacity of developing nations, and deliver more impactful contributions towards realizing SDG 15 both within China and on a global scale.

Integrated Evaluations and Interactions among SDGs

Background

The Sustainable Development Goals encompass a wide array of intricate and multifaceted issues, with interwoven relationships between different goals, primarily manifested as synergistic and trade-off effects. Specifically, synergistic effects denote the phenomenon where achieving a particular goal simultaneously enhances the improvement of other goals—highlighting the mutually beneficial relationships between them. Conversely, trade-off effects signify that while pursuing one goal, it might necessitate sacrificing other goals, leading to a delicate balance (Pradhan *et al*., 2017; Zhang *et al*., 2022b). Synergies and trade-offs are not confined solely within a single region; they also widely exist across different geographic regions due to human interactions, economic and trade activities, cultural exchange, material transfers, and other dynamics—referred to as spatial spillover effects.

Owing to disparities in natural resource endowments and socio-economic development levels, diverse regions encounter unique challenges concerning the interactions among SDGs during their development processes. Therefore, conducting SDGs' integrated evaluations is crucial. This involves elucidating the cross-relationships between SDG indicators in various regions, dynamically simulating the realization of SDGs under different developmental scenarios, and devising context-specific sustainable development pathways. This endeavor will contribute significantly to the achievement of the 2030 Agenda.

Leveraging geospatial modeling and simulation techniques based on Big Earth Data can effectively uncover the interconnectedness among SDGs across distinct regions and unveil their potential impact mechanisms and key determinants. Additionally, simulating future sustainable development scenarios through the interactions of SDGs at geographical spatial units facilitates dynamic projections of SDGs' realization, thereby supporting integrated and cross-evaluation of SDGs.

Over the past four years, our reports conducted integrated assessments of sustainable development progress in typical regions of China, delving into the synergies and trade-offs among SDG indicators at the provincial level. In 2023, this report will extend its scope to the prefecture or above level across China, evaluating sustainable development processes and how balanced development is. It will delve deeper into the interactions among SDG indicators across different cities. This chapter will also forecast the future developmental processes and trends of various cities in China, aiming to inform decisions on sustainable development at the prefecture or above level nationwide, thereby contributing to the achievement of SDGs across the entire country.

Integrated and Interaction Analysis of SDGs in Cities at or above the Prefecture Level of China

This chapter, based on the SDG indicator framework proposed by the United Nations and informed by China's sustainable development practices, establishes a comprehensive set of 61 indicators under 16 SDGs (excluding SDG 14) for 285 Chinese cities. This indicator framework is designed according to the principles of adaptability, measurability, comparability, wide coverage, and multiple timeframes. Through this framework, the chapter conducts assessments of comprehensive SDG progress, analyzes synergies and trade-offs among SDGs, investigates spatial spillover effects of SDGs, and simulates future SDG scenarios. The outcomes of these analyses can provide decision-makers with valuable insights for implementing and adjusting sustainable development pathways across various Chinese cities.

Integrated Assessment of Progress on SDGs

Referencing the United Nations Sustainable Development Goals Progress Chart methodology (UN, 2020b), the status of each SDG score for urban clusters and non-urban clusters in China for the year 2020 is calculated, along with the distance to achieving SDGs and the development trends of each SDG from 2010 to 2020. The status of 2020 SDG score is divided into five levels based on a 20% threshold: target met or almost met, close to target, moderate distance to target, far from target, and very far from target. The development trends of each SDG from 2010 to 2020 are classified into four levels based on the SDG score growth rate: substantial progress/on track, fair progress but acceleration needed, limited or no progress, and deterioration. Additionally, the SDG Composite Index score for each city is calculated, and an improved radar chart method is used to calculate the balance score for different cities (Liu *et al*., 2021). SDG balance is measured based on the score differences among SDGs, reflecting the level of balance in SDG development.

From 2010 to 2020, China's 285 cities at or above the prefecture level made significant progress in sustainable development. Urban clusters outperformed non-urban clusters in achieving SDGs, with a more pronounced growth trend. Overall, these 285 cities have made good progress towards SDGs, whether located in urban clusters or not. SDG 1 (No Poverty) has been essentially achieved, and SDG 12 (Responsible Consumption and Production) is close. Challenges exist in achieving SDG 6 (Clean Water and Sanitation), SDG 10 (Reduced Inequalities), SDG 11 (Sustainable Cities and Communities), and SDG 13 (Climate Action). Notably, SDG 13 shows limited progress

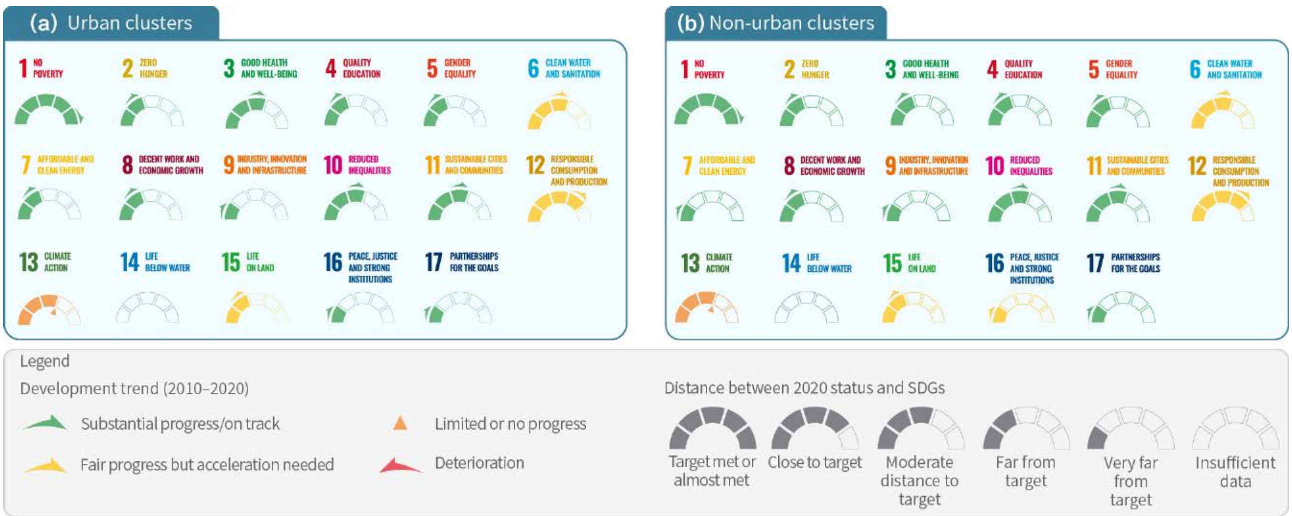
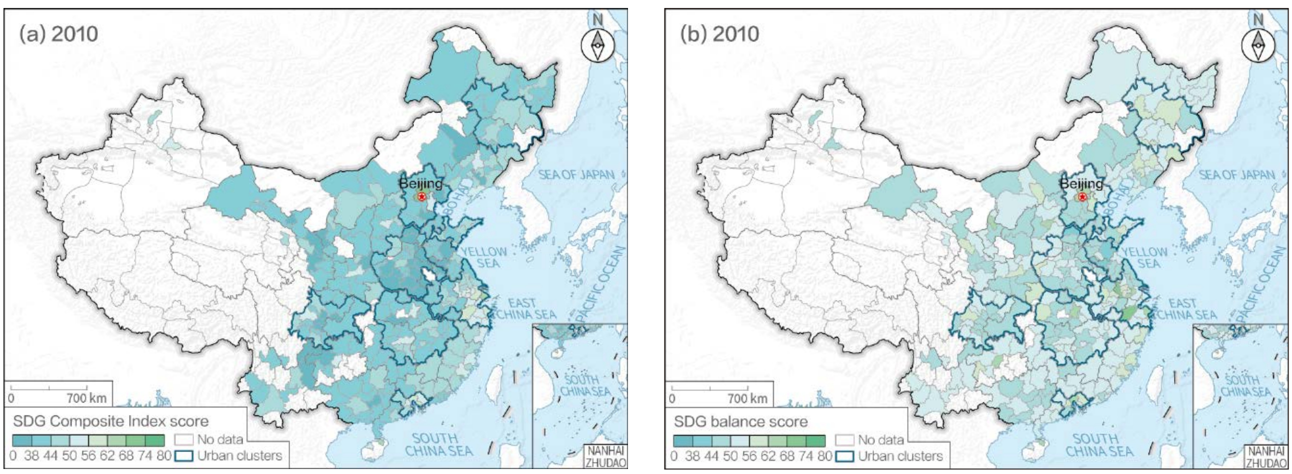


Figure 9-1 SDG progress dashboard of China's 285 cities at or above the prefecture level, 2010–2020



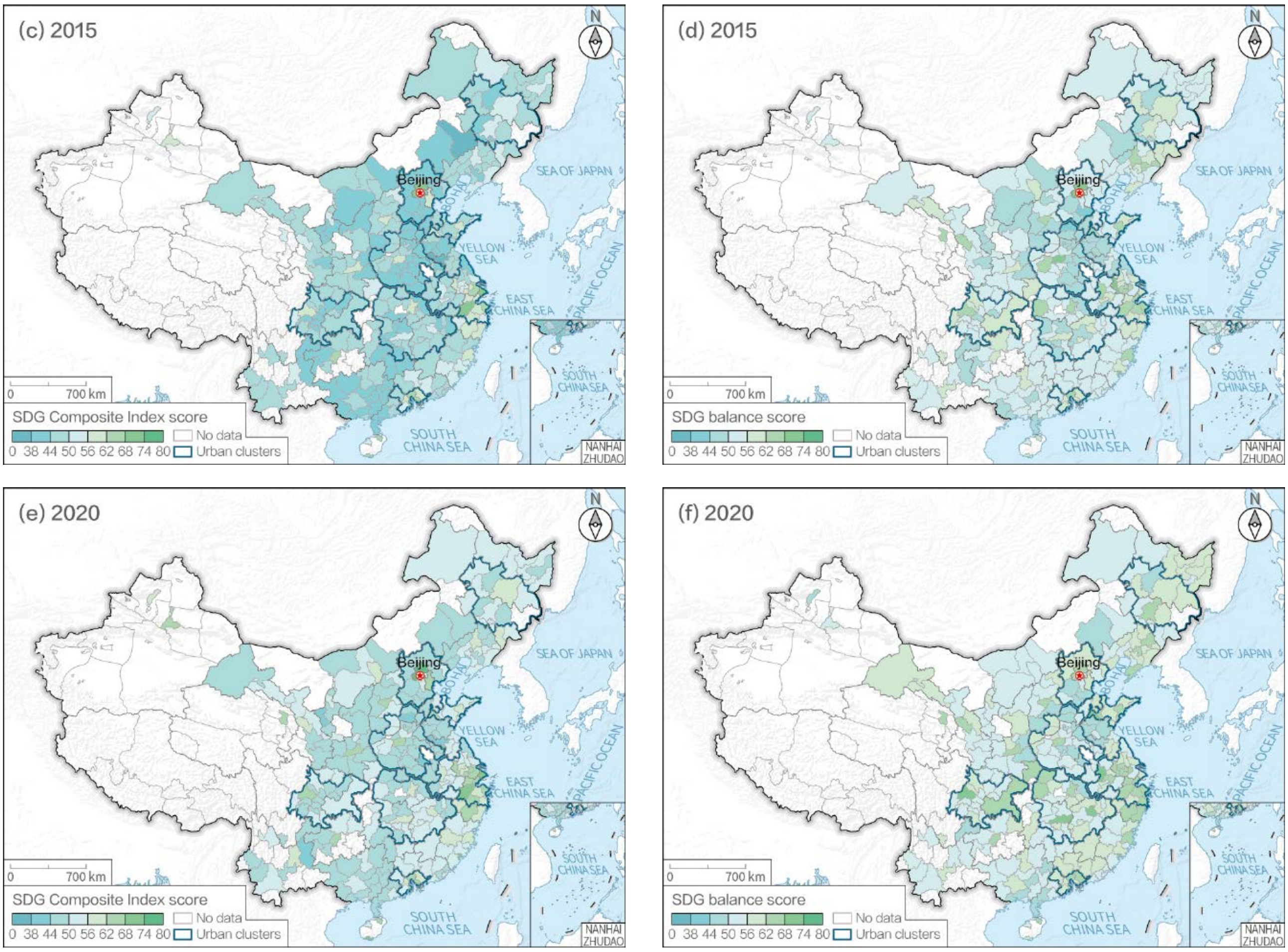


Figure 9-2 Integrated assessment of SDG progress in 285 cities at or above the prefecture level, 2010–2020

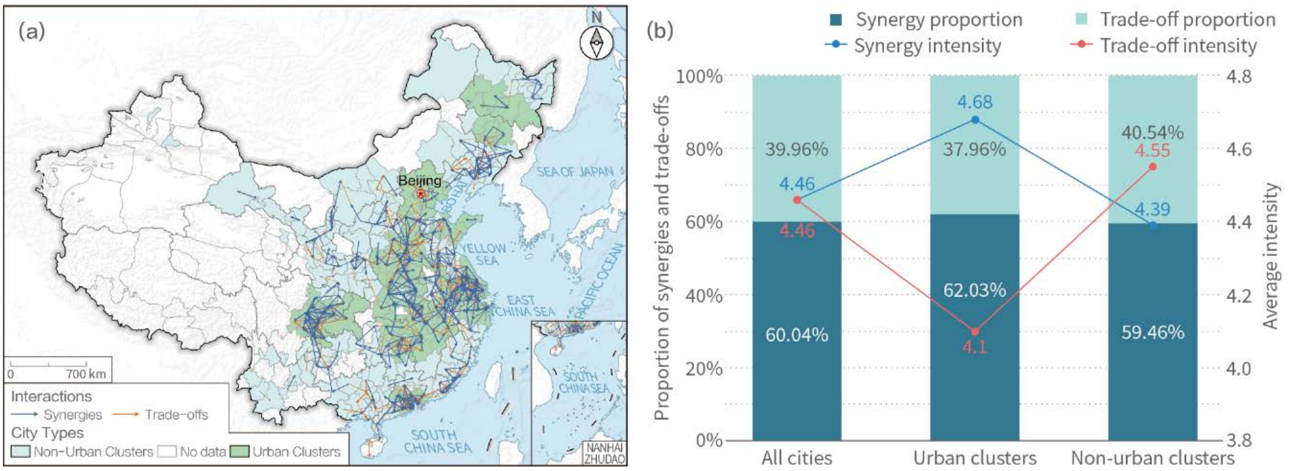
due to its primary indicator being carbon emissions. While SDG 2 (Zero Hunger), SDG 4 (Quality Education), SDG 5 (Gender Equality), and SDG 8 (Decent Work and Economic Growth) face significant challenges, they exhibit a rapid development trend. Both SDG 3 (Good Health and Well-being) and SDG 7 (Affordable and Clean Energy) show fast development trends in both urban and non-urban clusters, with urban clusters having a more favorable status compared to non-urban clusters and a higher likelihood of achieving them by 2030 (Figure 9-1).

Chinese cities at or above the prefecture level have higher scores for balanced SDG development than for Composite Index. However, the growth trend of the Composite Index scores is more pronounced, especially among cities in urban clusters. Urban clusters not only enhance the overall performance of SDGs but also possess the capability to promote balanced development across SDGs. From 2010 to 2020, urban clusters in China demonstrated higher average scores in both SDG Composite Index and balance level, compared to non-urban clusters (Figure 9-2), and exhibited a more significant growth trend. For most cities, the growth rate of the SDG Composite Index score exceeded that of the balance score, particularly for cities with lower initial Composite Index score. Spatially, cities in the eastern regions not only had higher SDG Composite Index scores but also paid more attention to balanced development among SDGs, as evidenced by the most notable growth trend in balance scores. Cities in the northeast saw moderate improvements in both SDG Composite Index and balance scores, while cities in the central and western regions achieved more remarkable progress in enhancing the overall performance of SDGs. Generally, urban cluster cities with close socioeconomic ties, well-established infrastructure, balanced industrial distribution, emphasis on technological innovation, and effective environmental management are more likely to achieve SDGs. Additionally, different cities should formulate development strategies and paths that align with their geographical location, advantageous industries, foundational environment, developmental priorities, and the socioeconomic and environmental conditions of surrounding cities.

Analysis of SDGs Synergies and Trade-offs

Based on the time series data of SDGs from 285 Chinese cities at or above the prefecture level (2000–2020), we conducted stationarity tests, determined the optimal lag period using a vector autoregressive model, and analyzed the Granger causal relationships between SDG indicators. Utilizing the causal relationships among SDG indicators, we constructed a simultaneous equation system for SDGs interactions among cities, exploring the direction and strength of interactions among SDGs in different cities. We calculated the proportions and average intensities of synergies and trade-offs in SDGs interactions for both urban cluster and non-urban cluster cities.

The overall interactions among SDGs in Chinese cities exhibited a prevalence of positive synergies over trade-offs, with synergistic relationships accounting for 60.04% and trade-off relationships accounting for 39.96%. This pattern was particularly pronounced in regions such as the Yangtze River Delta, Chengdu-Chongqing, and the Pearl River Delta urban clusters, where interactions among SDGs were more tightly interconnected. Typical interactions among SDGs between Chinese cities from 2000 to 2020 are shown in Figure 9-3, indicating that synergistic relationships outnumbered trade-off relationships by approximately 1.5 times. The relationships among Chinese cities are interconnected, emphasizing that urban development is not an isolated effort of individual cities but rather influenced by the spatial spillover effects of neighboring cities. Spatially, regions with close interactions among SDGs between cities are predominantly located in urban cluster areas, especially within urban cluster regions like the Yangtze River Delta, Chengdu-Chongqing, and the Pearl River Delta. Synergies among SDGs interactions between cities are significantly higher in quantity and intensity compared to trade-offs, with urban cluster development facilitating positive synergistic interactions among cities. The comparison results indicated that both the proportion and intensity of synergistic relationships in the SDG Composite Index among urban cluster cities are higher than those in non-urban cluster cities, while the proportion and intensity of trade-off relationships are lower. In summary, the development strategy of urban clusters in China effectively promotes positive synergistic development among cities, while also restraining the counteracting effects of trade-offs among cities. This approach contributes to a holistic and sustainable development of cities.



↑ Figure 9-3 Interactions among SDGs in Chinese cities at or above the prefecture level, 2000–2020. (a) Spatial distribution of top 1% typical interactions; (b) Proportion of total interactions

Spatial Spillover Effects for SDGs

The impact of cross-interactions between cities and surrounding cities on SDG implementation is assessed by calculating global and local Moran's Index, as well as utilizing the spatial Durbin model. In the spatial Durbin model, the growth of SDG Composite Index is the dependent variable, while the growth of SDG Composite Index in neighboring areas serves as the core independent variable. Control variables include initial SDG Composite Index, economic development, social progress, environmental improvement, governance efficiency progress, and SDG coupling coordination degree.

SDG performance of Chinese cities is not only driven by internal factors within their respective regions, but also influenced by spatial spillover effects from surrounding cities. When the progress of SDGs in neighboring cities increases by 10%, it can lead to a 2.80% increase in local SDGs. Importantly, spatial spillover effects in urban clusters are significantly higher than those in non-urban clusters. Chinese cities exhibit significant synergy, and positive spatial spillover effects are observed in both urban clusters and non-urban clusters. This indicates a positive correlation between the development of SDGs in a local region and the development of adjacent cities. Cities with high and low SDG scores tend to cluster separately in space. Meanwhile, there is evident spatial heterogeneity in urban spatial interactions. The spatial autoregressive coefficient of urban clusters is 0.1340 (83.75%) higher than that of non-urban clusters, indicating significantly stronger spatial spillover effects in urban clusters. Specifically, when the progress of SDGs in surrounding cities increases by 10%, the SDGs of cities in urban clusters and non-urban clusters increase by 2.94% and 1.60% respectively. Furthermore, there is a significant negative correlation between the growth rate and the initial level of SDG Composite Index for Chinese cities, urban clusters, and non-urban clusters. This suggests that regions with lower initial SDG Composite Index scores exhibit a "latecomer advantage", experiencing faster development compared to regions with higher scores (Figure 9-4).

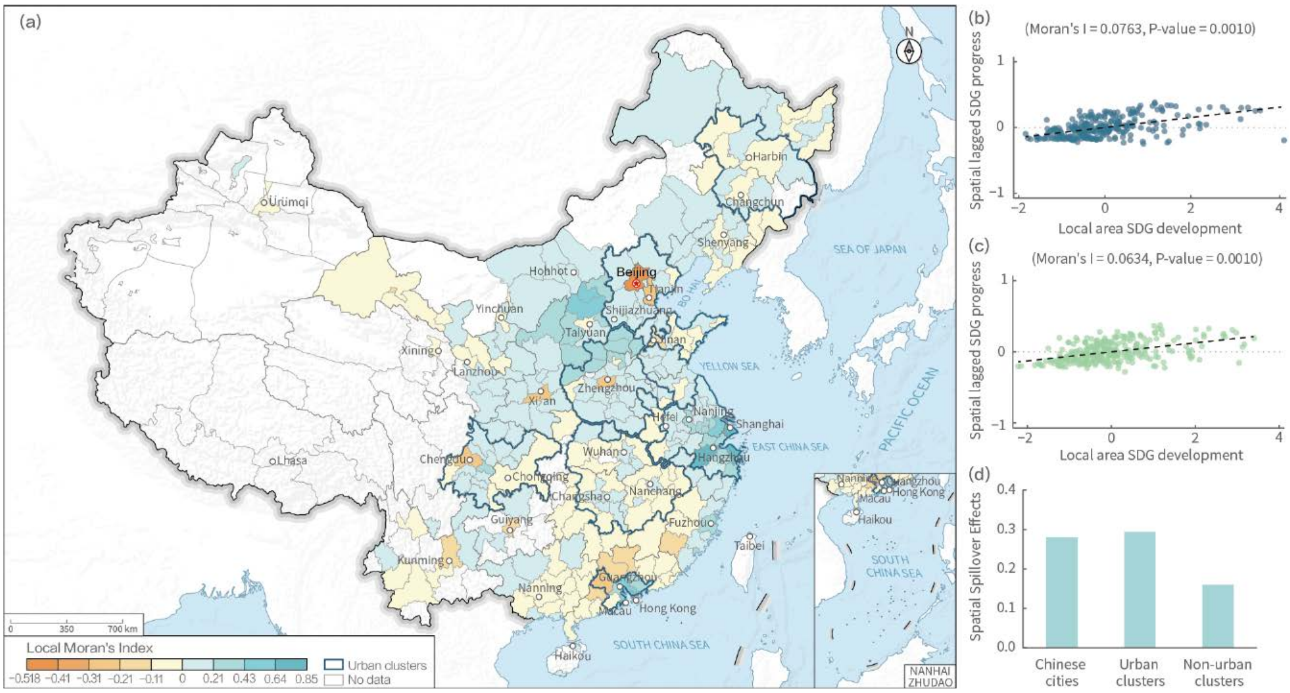
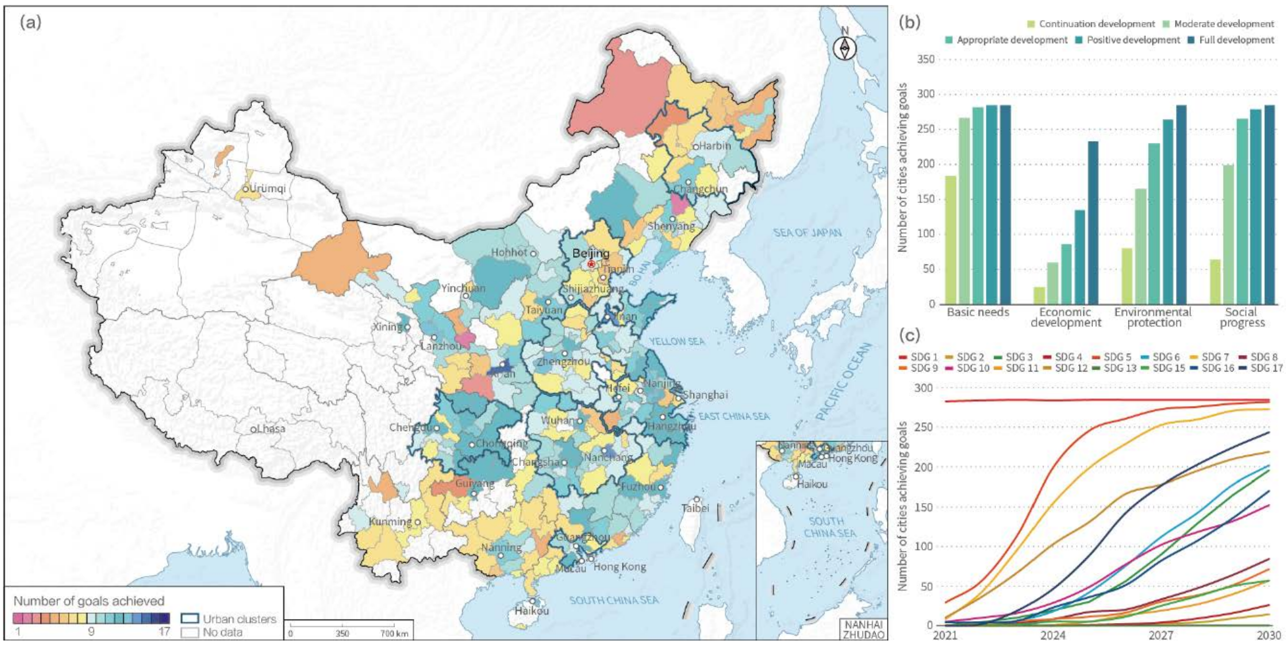


Figure 9-4 SDG spatial relationship between China's cities at or above the prefecture level. (a) SDG spatial aggregation features in 2020; (b) SDG interactions between focal city and neighboring cities in 2010; (c) SDG interactions between focal city and neighboring cities in 2020; (d) Spatial spillover effects

Projection of Future Development Scenarios for SDGs

Based on the SDGs data from various cities at or above the prefecture level in China from 2000 to 2020, annual average compound growth rates of SDGs for each city are calculated. Using the 2020 target values of SDGs, the distance to sustainability for cities in 2020 is constructed. A spatial geographical distance matrix among cities is established, and with the weight matrices of sustainability distance and spatial geographical distance, five distinct development paths: Continuation Development Path, Moderate Development Path, Appropriate Development Path, Active Development Path, and Full Development Path, are set. Similar neighboring city sets under different development paths are selected, and the best SDGs growth pattern among cities in the set is taken as a standard for learning. Meanwhile, considering the complex interrelationships within the SDGs system and the spatial spillover effects of SDGs within cities, the target values of city SDGs progress in the next year are predicted. Through iterative projection, target values of SDGs for each city at or above the prefecture level from 2021 to 2030 are obtained.

Projected future development of SDGs in various cities at or above the prefecture level in China exhibits significant spatial variations. The urban cluster strategy effectively propels sustainable development in cities. Emphasis should be placed on developing SDG 4 (Quality Education), SDG 11 (Sustainable Cities and Communities), SDG 12 (Responsible Consumption and Production), and SDG 15 (Life on Land) to promote the overall SDGs implementation. Scenario simulations reveal the projected results of SDGs progress in the Chinese cities by 2030, as depicted in Figure 9-5. Substantial disparities in SDGs progress under the Appropriate Development Path exist among different cities by 2030. The urban clusters such as the Yangtze River Delta and Chengdu-Chongqing exhibit more achievements in SDGs, while some cities in the northeast and southwest regions show lower SDGs completion, necessitating tailored strategies based on regional conditions. When categorizing SDGs into Basic Needs, Environmental Protection, Social Progress, and Economic Development, the completion of Basic Needs SDGs remains favorable across different development paths. As development costs increase, there is an increase in the number of cities achieving SDGs across the five development paths, most notably in the completion of Social Progress Goals. This suggests that appropriately raising the development cost can accelerate urban social



↑ Figure 9-5 Estimated results of SDGs progress in Chinese cities at or above the prefecture level by 2030. (a) Number of SDGs achievable by each city under appropriate development scenario; (b) Progress in achieving four types of SDGs under different scenarios; (c) SDGs development trends under appropriate development scenario, 2021–2030 sustainability. In terms of individual SDGs, SDG 1 (No Poverty) has been achieved. It is anticipated that by 2030, most cities will achieve Goals such as SDG 2 (Zero Hunger) and SDG 17 (Partnerships for the Goals), while SDG 4 (Quality Education), SDG 11 (Sustainable Cities and Communities), SDG 12 (Responsible Consumption and Production), and SDG 15 (Life on Land) still require focused efforts. Thus, rational policies are needed to promote quality education, actively build sustainable cities and communities, encourage the shift towards green production and consumption, and foster positive development of life on land, all of which will contribute to the overall realization of SDGs.

For the majority of cities in China, they can achieve SDG 5 (Gender Equality) and SDG 7 (Clean Energy) simply by continuing their current development paths or slightly increasing their development efforts. However, for SDG 2 (Zero Hunger), SDG 4 (Quality Education), and SDG 13 (Climate Action), most cities need to adopt the full development path, prioritizing food security, quality education, and climate change, to facilitate their overall realization of SDGs. The optimal implementation paths for China's cities at or above the prefecture level, as depicted in Figure 9-6, exhibit significant spatial variations, with urban cluster development strategies effectively promoting the attainment of SDGs. In urban clusters like the Yangtze River Delta and the Pearl River Delta, achieving SDG 8 (Decent Work and Economic Growth) and SDG 9 (Industry, Innovation, and Infrastructure) requires merely continuing the current development paths or adopting a moderate development path with limited additional investments. Conversely, cities in other regions may need higher investments (taking the active or full development paths) to realize SDG 8 and SDG 9.

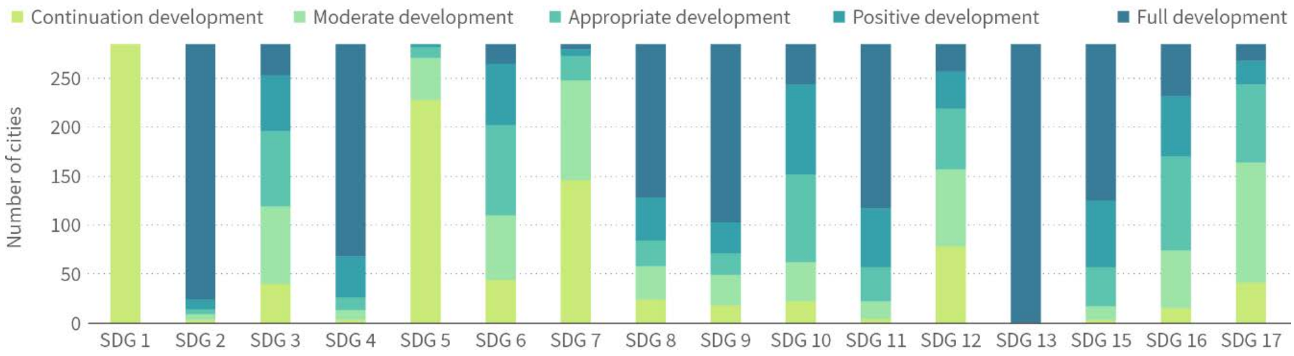


Figure 9-6 Number of cities at or above the prefecture level achieving each SDG under different development scenarios

Recommendations and Outlook

This chapter focuses on four main themes: SDGs integrated assessment, synergies and trade-offs, spatial spillover effects, and simulated future scenarios. Case studies were conducted at the scale of 285 cities at or above the prefecture level in China and found that there are significant spatial disparities in both the Composite Index and balanced development of SDGs among these cities; urban clusters exhibit better SDGs development compared to non-cluster areas; and synergistic SDGs relationships prevail over trade-off relationships in cities.

The research results can inform decision-making in China for accelerating urban cluster development, promoting synergistic SDGs development among different regions, mitigating trade-off effects, and selecting optimal sustainable development paths.

Based on the findings of this chapter, we propose the following recommendations:

1. Strengthen capacity for the acquisition of Big Earth Data on SDG indicators; develop an SDG indicator system suitable for different administrative levels in China such as city and county, aligning with the UN SDG indicators; establish standardized data collection processes to support multi-indicator interactions, integrated SDGs assessment and spatial spillover effects among cities.

2. Deepen research on methods for analyzing multi-indicator interactions and spillover effects; utilize exploratory spatial data analysis, spatial econometric models, and deep learning techniques with the aid of Big Earth Data to provide methodological references for investigating spatial spillover effects of multi-indicator interactions among China's cities at or above the prefecture level.

3. Conduct spatial decomposition research for non-spatial statistical SDG indicators; spatialize non-spatial statistical SDG indicators based on factors such as population and land use, to enable an integrated assessment of SDGs with high spatial resolution, providing technical support for adopting the right SDGs implementation paths in China's cities at or above the prefecture level.

In the future, we will continue to explore the information mining capacity of Big Earth Data in the realm of multi-indicator interactions and integrated assessment of SDGs. This exploration will provide a scientific basis for different regions to adopt suitable SDGs implementation paths.

Summary and Prospects

Summary

This report details case studies on seven SDGs (Zero Hunger, Clean Water and Sanitation, Affordable and Clean Energy, Sustainable Cities and Communities, Climate Action, Life Below Water, and Life on Land) and the interactions and integrated assessment of multiple SDG indicators at different scales, using Big Earth Data, from the perspectives of data products, methods and decision support.

In terms of data products, a total of 32 sets of global and China-scale data products were developed. Some of these products fill data gaps in SDG indicator monitoring, such as global large lakes and reservoirs transparency spatiotemporal variations, global wind and solar resource data, global World Heritage site boundaries, global 30 m forest cover data, global atmospheric particulate matter spatial distribution, China's daily $PM_{2.5}$ gridded data set, China's terraced field spatial distribution, China's forest aboveground biomass, and China's land degradation and restoration data sets. Other products enhance the spatial precision of SDG indicator monitoring and assessment, such as global 1 km resolution cropland water use efficiency, Africa's 0.5° grid groundwater storage change, and China's 10 m resolution raft aquaculture spatial distribution.

In terms of methods, 25 method models based on Big Earth Data were constructed. Some address the lack of SDG indicator monitoring methods, such as the method for assessing population proportion reliant on clean cooking fuels and technology in China. Others provide optimized solutions for SDG assessment, such as a cropland change monitoring model coupling continuous change detection and dynamic updating. Additionally, in the context of interactions and integrated assessment of multiple SDG indicators, SDGs spatiotemporal variations among different Chinese cities were explored using local spatial autocorrelation and bivariate spatial autocorrelation methods. The synergies and trade-offs of SDGs among cities were explored using the Granger causality test and simultaneous equation model. By building an iterative prediction model, SDGs progress and development trends in different scenarios for China's cities at or above the prefecture level were forecasted.

In terms of decision support, through the integration of the aforementioned data and methods, spatiotemporal analyses of SDG indicators were conducted, yielding 32 recommendations on both global and China's sustainable development efforts. For instance, in addressing regional factors driving farmland productivity enhancement, it is advised to embrace scientifically devised and comprehensive farmland construction approaches, including initiatives to enhance soil quality and leverage agricultural technology services to optimize the holistic benefits of farmland utilization. To rectify the challenge posed by imprecise guidance from statistical surveys, an extensive evaluation of clean water and sanitation facility usage among populations at both national and local scales is recommended, utilizing the continuous spatiotemporal satellite remote sensing data products. Additional recommendations include the incorporation of the proportion of non-hydropower renewable energy installations as a novel indicator for SDG 7.2, expediting the transition to cleaner energy sources; the advancement of intelligent and integrated urban public transportation, alongside meticulous planning and operation of public transportation routes tailored to specific needs; the resolute reduction of anthropogenic emissions coupled with measures to bolster ecosystem carbon sequestration, expediting global carbon neutrality; the augmentation of SDG 14.2 with an indicator for the restoration of typical marine ecosystems (e.g., mangroves, seagrass meadows, and coral reefs), aiming to enhance the quantifiability and accessibility of indicators, and encouragement of marine scientific research through the Decade of Ocean Science initiative; the reinforcement of assessment and simulation efforts pertaining to land degradation control and ecological restoration in border regions between China and Mongolia, leveraging Big Earth Data to mitigate the impact of sand and dust storms from the Mongolian Plateau; and the ongoing expansion of urban cluster strategies at China's cities at or above the prefecture level, with a particular focus on SDG 4, SDG 11, SDG 12, and SDG 15, fostering the comprehensive realization of SDGs.

Building on these foundations and utilizing the outcomes of the past four years' reports and national and United Nations statistics, an analysis was conducted of China's progress on primarily environmental SDG indicators from 2010 to 2022. The results demonstrate remarkable progress on environmental sustainable development indicators and overall stable improvement of all assessed indicators. By 2022, out of the 98 indicators evaluated using Big Earth Data, 52% (51 indicators) had already been achieved ahead of schedule.

Prospects

While SDGs have been significantly promoted by the widespread application of Big Earth Data, their implementation still face a multitude of challenges, such as the needs for higher-quality Big Earth Data, more rational and intelligent methods for SDG indicator assessment, data sharing and utilization, and an integrated evaluation system for multiple indicators (Guo *et al*., 2022a; Guo *et al*., 2022b; Guo *et al*., 2021). To advance the realization of the United Nations 2030 Agenda, the following key actions are recommended:

Promote the calibration and adjustment of the SDG indicator framework

Currently, some indicators within the UN SDG framework do not adequately capture variations in population, development levels, and geographical environments among countries. Additionally, national-level statistical data fall short in capturing disparities in sustainable development across different geographical regions within nations, thereby impeding the comprehensive realization of the "leave no one behind" principle. Harnessing the robust spatial decomposition capability of Big Earth Data, particularly for environmental indicators, has the potential to enable a more comprehensive spatial monitoring and assessment of SDG indicators. To address these limitations, it is recommended that the application of relevant indicators based on Big Earth Data be actively promoted within the SDG indicator framework, serving as a geospatial decomposition complement, facilitating a more precise calibration and enhancement of the SDG indicator system.

Promote the sharing and widespread application of Big Earth Data

Due to variations in statistical standards and methodologies across nations, there are discrepancies in the standardization and quality of indicator data, and significant disparities in geographical coverage and timeliness exist between data from developed and developing countries. Big Earth Data offers unique advantages in terms of its extensive scope, integration of multiple sources, precision, scientific rigor, and timeliness. Establishing a well-organized management framework and efficient sharing mechanism for this vast pool of Big Earth Data is essential for advancing the SDGs.

Currently, the sharing of Big Earth Data faces challenges, including insufficient sharing mechanisms, limited innovation in sharing technologies, homogeneous service models, and inadequate protection of sharing rights. To fully harness the potential of Big Earth Data in achieving global SDGs, it is essential to encourage broader data sharing and utilization, improve the management and integration of temporal and spatial data, establish mechanisms for sharing scientific data, and eliminate data barriers, thus bridging the digital divide.

Drive technological innovation for SDG assessment

Novel methods and models for monitoring SDG indicators based on Big Earth Data require advancements in automation, intelligence, and timeliness before they can be efficiently utilized. The isolated application of existing mining and analytical theories and methods from a single domain is no longer effective for driving scientific discoveries. Comprehensive application and innovative technological approaches are needed to systematically address significant scientific challenges. While current Big Earth Data analysis methods mainly involve statistical analysis, visualization, and machine learning technologies, we recommend further enhancing the applicability and interpretability of these methods by integrating cutting-edge technologies such as artificial intelligence, deep learning, data fusion, data assimilation, and blockchain, thereby raising the capacity of Big Earth Data to assess SDGs.

Enhance the big data-enabled study of relationships between multiple SDGs

The United Nations 2030 Agenda provides a comprehensive and multi-dimensional development perspective. Due to the interrelations among different SDGs, the pursuit of a single goal may be promoted or constrained by other goals. Big Earth Data's spatiotemporal continuity can complement or replace traditional official statistical data, providing multi-topic information encompassing land, atmosphere, oceans, and population. It is necessary to harness an abundance of multi-source information to promote the cross-sectoral monitoring capabilities across global, national, or regional levels, supporting problem-oriented data mining and exploring the construction of a multi-indicator integrated assessment system. It is essential to thoroughly analyze synergies or trade-offs among different SDGs, precisely track indicator trends, optimize regional SDG synergistic development pathways, and provide a scientific basis for the collective advancement of all SDGs.

Promote the utilization of data from the Sustainable Development Science Satellite

The Sustainable Development Science Satellite-1 (SDGSAT-1), launched by the International Research Center of Big Data for Sustainable Development Goals, stands as the world's pioneering scientific satellite tailored to the service of the 2030 Agenda. It offers exclusive data support for SDG indicators that elucidate the interplay between humanity and the environment. In September 2022, the SDGSAT-1 Open Science Program was initiated, engaging over 70 countries in harnessing satellite data. It is recommended that the international community widely employ SDGSAT-1 data, a novel data source that can make substantial contributions to SDGs research worldwide, particularly in developing nations. Concurrently, exploring the application potential of Big Earth Data in terms of data quality, processing methodologies, spatial precision, and data granularity is recommended to fully leverage its role in evaluating the attainment of SDGs.

Data Sources

Satellite Data

China forest cover change data sets (CFCD) for the years 1980 to 2015. https://doi.org/10.1029/2022JG007101

Global land cover change data (LUH2) for the years 1980 to 2022. https://luh.umd.edu/

Global wetland distribution data (WAD2M) for the years 2000 to 2018. https://doi.org/10.5194/essd-13-2001–2021

Global Enhanced Vegetation Index (EVI) Data at 500 m resolution for the years 2000 to 2020. https://lpdaac.usgs.gov/products/myd13a1v061/

Monthly OMI satellite global tropospheric NO_2 column concentration data for the years 2010 to 2012 and 2021. https://www.temis.nl/airpollution/no2col/no2regioomimonth_qa.php

China land use data at 30 m resolution for the years 2010 to 2021. https://zenodo.org/record/5816591#.Y-4bEsisGvM

China MODIS aerosol optical thickness data at 1 km resolution for the years 2010 to 2021. https://zenodo.org/record/5652257

Monthly MODIS Vegetation Index Product (MOD13A3) at 1 km resolution for the years 2010 to 2022. https://modis.gsfc.nasa.gov/

Monthly OMI satellite China tropospheric NO_2 column concentration data at 0.1° resolution for the years 2013 to 2018. https://zenodo.org/record/7574177

Global land cover data for the years 2015 and 2020, from the European Space Agency (ESA) at 300 m resolution. http://due.esrin.esa.int/page_globcover.php

China double-cropping rice distribution data for the years 2016 to 2022. https://doi.org/10.3390/rs13224609

China middle-season rice distribution data for the years 2017 to 2022. https://doi.org/10.5194/essd-2023-9

Monthly TROPOMI Satellite China tropospheric NO_2 column concentration data at 1 km resolution for the years 2019 to 2020. https://zenodo.org/record/6622056

Global TROPOMI NO_2 column concentration data for the years 2019 to 2022, from the European Space Agency (ESA). www.esa.int

Global land cover data (GlobleLand30) for the year 2020. http://www.globallandcover.com/

Global Fine Land Cover Classification Product (GLC_FCS30) at 30 m resolution for the year 2020. https://data.casearth.cn/thematic/glc_fcs30

AquaSat shared data set. https://github.com/GlobalHydrologyLab/AquaSat

European Multi Lake Survey (EMLS) shared data set. http://geonode.org/

Open source satellite remote sensing image data from Google Earth Pro. http://www.google.com/

GRACE satellite gravity data. http://icgem.gfz-potsdam.de/series

KeyHole satellite remote sensing image data (1962). https://www.earthdata.nasa.gov/

Landsat satellite remote sensing image data. https://www.earthdata.nasa.gov/

MODIS satellite remote sensing image data. https://www.earthdata.nasa.gov/

MODIS normalized difference vegetation index (NDVI) data. https://doi.org/10.5067/MODIS/MYD13Q1.061

Planet satellite remote sensing image data. https://www.planet.com/explorer/

Sentinel satellite remote sensing image data. https://scihub.copernicus.eu/

SPOT satellite remote sensing image data. https://regards.cnes.fr/user/swh/modules/60

SRTM global land elevation data. https://earthexplorer.usgs.gov/

Sustainable Development Science Satellite-1 (SDGSAT-1) remote sensing image data. https://www.sdgsat.ac.cn/

Gaofen satellite remote sensing image data. https://data.cresda.cn/#/home

National soil information grid data. http://doi.org/10.11666/00073.ver1.db

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Network Data

Under the authorization of Weibo, publicly accessible Weibo posts and corresponding user profiles were automatically retrieved using a Python 3.6 program through an application interface. The collected data was from the time range from January 1, 2022, to December 31, 2022.

Acronyms & Abbreviations

AGB	Aboveground Biomass
BP	British Petroleum
CBAS	International Research Center of Big Data for Sustainable Development Goals
CBD	Convention on Biological Diversity
CDIAC	Carbon Dioxide Information Analysis Center
CLSM	Catchment Land Surface Model
DEM	Digital Elevation Model
DSDI	Dust Storm Detection Index
EDGAR	Emissions Database for Global Atmospheric Research
EMLS	European Multi Lake Survey
FAO	Food and Agriculture Organization of the United Nations
FUI	Forel-Ule Index
GCP	Global Carbon Project
GDI	Global Development Initiative
GDP	Gross Domestic Product
GLAKES	Global Lakes
GLDAS	Global Land Data Assimilation System
GLHYMPS	GLobal HYdrogeology MaPS
GPCC	Global Precipitation Climatology Centre
GPG	Good Practice Guidance
GRACE	Gravity Recovery and Climate Experiment
GSW	Global Surface Water
HIST	International Centre on Space Technologies for Natural and Cultural Heritage under the auspices of UNESCO
IBIS	Integrated BIosphere Simulator
IEA	International Energy Agency
IPCC	Intergovernmental Panel on Climate Change
ISO/TC339	Technical Committee 339 Small Hydropower Plants of International Organization for Standardization
IUCN	International Union for Conservation of Nature
JRC	European Commission's Joint Research Centre
LDN	Land Degradation Neutrality
MODIS	Moderate Resolution Imaging Spectroradiometer
NDCs	Nationally Determined Contributions

NPP	Net Primary Productivity
OLI	Operational Land Imager
PCAPT	Public Convenient Accessibility to Public Transport
PE	Polyethylene
PET	Polyethylene Terephthalate
POI	Points of Interest
PP	Polypropylene
PS	Polystyrene
RLI	Red List Index
RUSLE	Revised Universal Soil Loss Equation
SDGs	Sustainable Development Goals
SDS	Sand and Dust Storms
UNCCD	United Nations Convention to Combat Desertification
UNIDO	United Nations Industrial Development Organization
WDPA	World Database on Protected Areas
WHC	UNESCO World Heritage Centre
WHO	World Health Organization

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Core Team of Authors

Leading author

Guo Huadong	International Research Center of Big Data for Sustainable Development Goals

Authors (Alphabetically arranged)

Cao Bowen	Tsinghua University
Cao Min	Nanjing Normal University
Chen Fang	International Research Center of Big Data for Sustainable Development Goals
Chen Min	Nanjing Normal University
Chen Shuangshuang	Zhejiang University
Chen Yu	International Research Center of Big Data for Sustainable Development Goals
Cui Meng	Beijing Jipeng Investment Information & Consultant Ltd.
Deng Siming	International Research Center of Big Data for Sustainable Development Goals
Dong Guofeng	International Center on Small Hydro Power
Dong Jinwei	Institute of Geographic Sciences and Natural Resources Research, Chinese Academy of Sciences
Dou Xinyu	Tsinghua University
Dou Changyong	International Research Center of Big Data for Sustainable Development Goals
Du Zhenrong	Tsinghua University
Feng Lian	Southern University of Science and Technology
Fu Dongjie	Institute of Geographic Sciences and Natural Resources Research, Chinese Academy of Sciences
Gu Haifeng	Third Institute of Oceanography, Ministry of Natural Resources
Guo Yaqi	Nanjing Normal University
Guo Yanjun	Institute of Geographic Sciences and Natural Resources Research, Chinese Academy of Sciences
Han Qunli	Aerospace Information Research Institute, Chinese Academy of Sciences
Han Yan	Institute of Zoology, Chinese Academy of Sciences
He Guojin	Aerospace Information Research Institute, Chinese Academy of Sciences
He Qisheng	Hohai University
He Shu	International Research Center of Big Data for Sustainable Development Goals
Hu Bo	Institute of Atmospheric Physics, Chinese Academy of Sciences
Hu Zaiyuan	Institute of Oceanology, Chinese Academy of Sciences
Huang Bo	University of Hong Kong
Huang Chunlin	Northwest Institute of Eco-Environment and Resources, Chinese Academy of Sciences
Huang Jinxia	National Science Library, Chinese Academy of Sciences
Huang Kan	Fudan University
Huang Lei	International Research Center of Big Data for Sustainable Development Goals
Huang Rongyong	Guangxi University

Huang Yan	International Center on Small Hydro Power
Ji Liqiang	Institute of Zoology, Chinese Academy of Sciences
Jia Gensuo	International Research Center of Big Data for Sustainable Development Goals
Jia Huicong	International Research Center of Big Data for Sustainable Development Goals
Jia Li	Aerospace Information Research Institute, Chinese Academy of Sciences
Jia Lingping	Gansu Natural Energy Research Institute
Jia Shaofeng	Institute of Geographic Sciences and Natural Resources Research, Chinese Academy of Sciences
Jiang Min	Aerospace Information Research Institute, Chinese Academy of Sciences
Jiang Yunzhong	China Institute of Water Resources and Hydropower Research
Ke Piyu	Tsinghua University
Li Wenyu	Chinese University of Hong Kong
Li Dong	Institute for China Sustainable Urbanization, Tsinghua University
Li Huixiang	Capital Normal University
Li Jie	Northwest Normal University
Li Jingxi	First Institute of Oceanography, Ministry of Natural Resources
Li Junsheng	International Research Center of Big Data for Sustainable Development Goals
Li Liping	Aerospace Information Research Institute, Chinese Academy of Sciences
Li Shihua	Sun Yat-Sen University
Li Xiaosong	International Research Center of Big Data for Sustainable Development Goals
Li Xinwu	International Research Center of Big Data for Sustainable Development Goals
Li Yimeng	Chongqing Jiaotong University
Li Zhuo	Institute of Agricultural Resources and Regional Planning, Chinese Academy of Agricultural Sciences
Liang Dong	International Research Center of Big Data for Sustainable Development Goals
Lin Congtian	Institute of Zoology, Chinese Academy of Sciences
Liu Lin	Beijing Jipeng Investment Information & Consultant Ltd.
Liu Boya	Institute of Atmospheric Physics, Chinese Academy of Sciences
Liu Jie	International Research Center of Big Data for Sustainable Development Goals
Liu Liangyun	International Research Center of Big Data for Sustainable Development Goals
Liu Saimiao	Aerospace Information Research Institute, Chinese Academy of Sciences
Liu Shaobo	International Centre on Space Technologies for Natural and Cultural Heritage under the auspices of UNESCO
Liu Wenna	China University of Geosciences, Beijing
Liu Xiwen	National Science Library, Chinese Academy of Sciences
Liu Yu	Chinese University of Hong Kong
Liu Zhu	Tsinghua University
Lu Qi	Institute of Ecological Protection and Restoration, Chinese Academy of Forestry
Lu Shanlong	International Research Center of Big Data for Sustainable Development Goals
Luo Lei	International Research Center of Big Data for Sustainable Development Goals
Meng Jihua	International Research Center of Big Data for Sustainable Development Goals

Miao Junxia	Lanzhou University
Miao Shuqi	Hohai University
Niu Zheng	Aerospace Information Research Institute, Chinese Academy of Sciences
Pan Jianping	Chongqing Jiaotong University
Pan Yun	Capital Normal University
Peng Dailiang	International Research Center of Big Data for Sustainable Development Goals
Pi Xuehui	Southern University of Science and Technology
Qi Chen	Chongqing Jiaotong University
Qiu Shuang	National Climate Centre
Ren Jingzheng	Hong Kong Polytechnic University
Shangguan Donghui	Northwest Institute of Eco-Environment and Resources, Chinese Academy of Sciences
Shang Liping	Gansu Natural Energy Research Institute
Shen Tong	International Research Center of Big Data for Sustainable Development Goals
Shi Wenjiao	Institute of Geographic Sciences and Natural Resources Research, Chinese Academy of Sciences
Song Jing	World Resources Institute
Song Xiaoyu	Northwest Institute of Eco-Environment and Resources, Chinese Academy of Sciences
Sun Chengjun	First Institute of Oceanography, Ministry of Natural Resources
Sun Chunlei	Center of Engineering and Construction Service, Ministry of Agriculture and Rural Affairs, PRC
Sun Song	Institute of Oceanology, Chinese Academy of Sciences
Sun Xiaoxia	Institute of Oceanology, Chinese Academy of Sciences
Sun Zhongchang	International Research Center of Big Data for Sustainable Development Goals
Qin Haining	Institute of Botany, Chinese Academy of Sciences
Qin Xiaofei	Fudan University
Tang Jing	National University of Singapore
Teng Yishu	Beijing Normal University
Tian Qingqing	China Institute of Water Resources and Hydropower Research
Tian Yichen	Aerospace Information Research Institute, Chinese Academy of Sciences
Tian Yu	China Institute of Water Resources and Hydropower Research
Wang Chengyi	Aerospace Information Research Institute, Chinese Academy of Sciences
Wang Xuhua	Beijing Jipeng Investment Information & Consultant Ltd.
Wang Zujia	Aerospace Information Research Institute, Chinese Academy of Sciences
Wang Fang	China Energy Efficiency Investment and Assessment Committee, China Energy Research Society
Wang Futao	Aerospace Information Research Institute, Chinese Academy of Sciences
Wang Juanle	Institute of Geographic Sciences and Natural Resources Research, Chinese Academy of Sciences
Wang Lizhe	China University of Geosciences, Wuhan
Wang Lili	Institute of Atmospheric Physics, Chinese Academy of Sciences
Wang Meng	Aerospace Information Research Institute, Chinese Academy of Sciences
Wang Minglei	Institute of Geographic Sciences and Natural Resources Research, Chinese Academy of Sciences
Wang Shaohua	International Research Center of Big Data for Sustainable Development Goals

Wang Shenglei	International Research Center of Big Data for Sustainable Development Goals
Wang Wenzhuo	China Electric Power Research Institute
Wang Xiaochuan	Nanjing Normal University
Wang Yagang	Gansu Natural Energy Research Institute
Wang Yang	National Climate Centre
Wang Yizhen	Tianjin University
Wei Xianhu	Aerospace Information Research Institute, Chinese Academy of Sciences
Wei Xinrui	International Center on Small Hydro Power
Wen Yanru	Institute of Agricultural Resources and Regional Planning, Chinese Academy of Agricultural Sciences
Wu Mingquan	Aerospace Information Research Institute, Chinese Academy of Sciences
Wu Bingfang	Aerospace Information Research Institute, Chinese Academy of Sciences
Wu Jiaping	Zhejiang University
Xia Lili	Aerospace Information Research Institute, Chinese Academy of Sciences
Xia Xiaosheng	Sun Yat-Sen University
Xiao Huijuan	Hong Kong Polytechnic University
Xie Liwei	Institute for China Sustainable Urbanization, Tsinghua University
Xie Yihan	International Research Center of Big Data for Sustainable Development Goals
Xu Weihua	Research Center for Eco-Environmental Sciences, Chinese Academy of Sciences
Xu You	Institute of Geographic Sciences and Natural Resources Research, Chinese Academy of Sciences
Xu Zhenci	University of Hong Kong
Yan Dongmei	International Research Center of Big Data for Sustainable Development Goals
Yan Haoran	Southern University of Science and Technology
Yan Shijie	Aerospace Information Research Institute, Chinese Academy of Sciences
Yang Ruixia	International Research Center of Big Data for Sustainable Development Goals
Yang Xiao	National Climate Centre
Yang Ziyu	International Research Center of Big Data for Sustainable Development Goals
Ye Zhanjiang	Zhejiang University
Yin Zhiqiang	Command Center of Natural Resources Comprehensive Survey, China Geological Survey
You Xinyan	International Research Center of Big Data for Sustainable Development Goals
Yu Qiang	State Grid Smart Internet of Vehicles Co., Ltd
Yu Rencheng	Institute of Oceanology, Chinese Academy of Sciences
Yu Qiangyi	Institute of Agricultural Resources and Regional Planning, Chinese Academy of Agricultural Sciences
Yu Le	Tsinghua University
Yuan Wenping	Sun Yat-Sen University
Zhang Bing	Aerospace Information Research Institute, Chinese Academy of Sciences
Zhang Chong	China Power International Development Limited
Zhang Chong	Capital Normal University
Zhang Di	First Institute of Oceanography, Ministry of Natural Resources

Zhang Kaijiao	Macao University of Science and Technology
Zhang Tianyi	Institute of Atmospheric Physics, Chinese Academy of Sciences
Zhang Xiaomei	Aerospace Information Research Institute, Chinese Academy of Sciences
Zhang Xiao	International Research Center of Big Data for Sustainable Development Goals
Zhang Yu	Institute of Geographic Sciences and Natural Resources Research, Chinese Academy of Sciences
Zhao Licheng	International Research Center of Big Data for Sustainable Development Goals
Zhao Tingting	International Research Center of Big Data for Sustainable Development Goals
Zheng Chaolei	Aerospace Information Research Institute, Chinese Academy of Sciences
Zheng Xinman	National Science Library, Chinese Academy of Sciences
Zhou Mingru	Hohai University
Zhou Qi	China University of Geosciences, Wuhan
Zhou Wei	China University of Geosciences, Beijing
Zhu Hanwu	Beijing Jipeng Investment Information & Consultant Ltd.
Zou Yarong	National Satellite Ocean Application Service
Zuo Lijun	Aerospace Information Research Institute, Chinese Academy of Sciences

Contact us:
Add.: No.9 Dengzhuang South Road, Haidian District
Beijing 100094, China
Tel.: +86 10 82177823
Email: secretariat@cbas.ac.cn
http://www.cbas.ac.cn

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