Received: 30 June 2023 | Revised: 29 August 2023 | Accepted: 7 September 2023 | Published online: 8 September 2023

CASE STUDY

Green and Low-Carbon Economy
2026, Vol. 4(1) 129–135
DOI: 10.47852/bonviewGLCE32021306

Digitalization and Climate Change Adaptation in China

Daoping Wang[1,2,*]

[1]*Department of Geography, King's College London, UK*

[2]*Department of Computer Science and Technology, University of Cambridge, UK*

Abstract: The effects of climate change are increasingly transforming natural environments, threatening human living and socioeconomic developments. While mitigation action remains a priority, government efforts must also focus on helping people adapt to today's climate impacts. Emerging digital technologies, which provide more efficient, rapid, and reliable risk monitoring and forecasting and enable better decision-making, can play a critical role to this end. This study develops policy recommendations for the utilization of digital tools to enhance climate change adaptation in China. This article first identifies China's primary climate change adaptation challenges, followed by an examination of successful digital solutions from countries outside of China. Successful application cases include using advanced machine learning models to develop more accurate rainfall predictions and applying digital twin systems to manage urban sewers in real time. These solutions are then evaluated in the Chinese context, leading to the formation of policy recommendations to advance similar initiatives.

Keywords: climate change adaptation, artificial intelligence, digital twins, data standards, data-sharing policy

1. Introduction

The ramifications of climate change are continuously and progressively reshaping the habitats and environments that humans inhabit. These alterations, brought about by rising temperatures, unpredictable weather patterns, and shifts in ecological balances, have a profound impact on our ways of life. While mitigation efforts, aimed at reducing greenhouse gas emissions and slowing global warming, continue to be crucial in our fight against climate change, it is also paramount that government initiatives extend to facilitating and supporting the adaptation of communities to the evolving climate conditions.

These adaptations could take various forms, from building resilience against climate-induced natural disasters to altering agricultural practices in response to changing precipitation patterns and temperature fluctuations. In short, while we strive to minimize our impact on the climate, we must also prepare for and adjust to the climate's impact on us. Consequently, policy measures must strive for a dual-purpose approach: continuing the critical task of mitigation, while also giving due importance to adaptation strategies to better cope with the realities of current and imminent climate impacts.

The advent of digital technologies has the potential to significantly contribute to our response to climate change. These tools, including artificial intelligence (AI), machine learning, big data, and remote sensing, provide a more robust, swift, and dependable means of monitoring climate risks and forecasting their potential impacts. By processing vast amounts of data, these technologies can generate quantitative, actionable indicators that enable more informed and strategic decision-making. This capacity to swiftly process and interpret complex data can significantly enhance our ability to anticipate, prepare for, and respond to climate events.

In China, a nation that has made remarkable strides in the field of digital technology, the role of such tools becomes even more pronounced. The Chinese digital economy, which has been rapidly expanding and innovating, provides a solid foundation for the integration of digital technologies in climate change adaptation strategies. Given this advancement in digital infrastructure, it becomes not only feasible but also imperative to employ these technologies to augment China's capabilities in adapting to climate change.

Harnessing digital technologies for climate adaptation in China is not just a necessary response to a global challenge, but it is also a well-founded approach, grounded in the nation's digital strengths. Furthermore, the potential benefits of this integration are immense, offering possibilities to revolutionize climate resilience efforts, create more sustainable cities, and ensure the safety and well-being of communities in the face of an uncertain climate future. The marriage of digital technologies and climate change adaptation presents an opportunity that China is uniquely positioned to seize and lead.

In this study, I develop policy recommendations for the use of digital tools to promote climate change adaptation in China. I first identify the major climate change adaptation challenges in China and then discuss high performing digital solutions developed and deployed in countries outside of China. Finally, I analyze these solutions in the context of China and provide policy recommendations for advancing similar approaches.

***Corresponding author:** Daoping Wang, Department of Geography, King's College London and Department of Computer Science and Technology, University of Cambridge, UK, Email: daoping.wang@kcl.ac.uk

2. Major Climate Change Adaptation Challenges in China

An analysis of climate change risk and adaptation challenges must begin with a typology against which the situation in China can be assessed. Following the risk framing in IPCC AR6 [1], I define risks and impacts. Risks are the potential for adverse consequences for ecological or human systems.[1] Impacts refer to the consequences of realized risks on natural and human systems. Climate change risks and impacts result from dynamic interactions between climate-related hazards and the level of exposure and vulnerability of the ecological or human system in question.[2] Under this framework, Figure 1 presents the major climate change risks facing China [2–4].

The main climate-related hazards in China can be grouped as (a) changes in climate conditions and (b) weather and climate extremes. Significant changes have been observed in China's annual mean temperature and precipitation characteristics over the past century [5]. The average surface air temperature of China increased by 0.98°C between 1901 and 2010, with a particular acceleration in warming since 1980. Mean temperature changes in China are projected to be higher than the global average, at an estimated 5°C increase by end of the century. Although there was no significant change observed in the annual average precipitation, there were recorded changes in the spatial and temporal distribution of precipitation. Changes in climate conditions also alter the severity of weather and climate extremes in China. According to the EM-DAT,[3] there have recorded 482 weather and climate extremes in China since 2001. The five most frequent extremes include flood (202 times), storm (192 times), landslide (53 times), drought (22 times), and extreme temperature (9 times).[4]

The main exposures include two categories, i.e., natural ecosystems and socioeconomic systems. In China, the vulnerability of natural ecosystems mainly lies in the socioeconomic development creating strain on water resources, terrestrial ecosystems, and coastal ecosystems. The vulnerability of the socioeconomic system mainly lies in the insufficient agricultural irrigation facilities, lack of risk-oriented planning of urban infrastructure, and the limited medical resources to cope human health.

Although China has taken some adaptation actions for reducing above-mentioned hazards, exposure, or vulnerability, there are still many residual risks that have not been coped and adapted. According to Climate Risk Country Profile of China [2], the major impacts (realized risk) include water scarcity; soil degradation, dryland expansion, and desertification; coastal erosion rates and saltwater intrusion; productivity loss of the agriculture sector and food security; disruption of operation of urban infrastructures and broader economies; increase in heat-related mortality; increase in water- and vector-borne diseases; and malnutrition. These are also the main risks that need to be adapted in the future in China.

To cope above climate change risks and impacts, the Chinese National Climate Change Adaptation Strategy 2035 [3] point to the following three adaptation priorities for reducing climate change risks in China (Figure A1):

1) Strengthening climate change monitoring, early warning, and risk management.
2) Improving the climate change adaptation ability of nature ecosystems, including water resource, terrestrial ecosystem, and coastal zone.
3) Improving the climate change adaptation ability of socioeconomic systems, including agriculture, urban systems, and human health.

Given the above major climate change adaptation challenges and adaptation priorities of China, in Section 3 we will explore international cases in the areas of climate change monitoring and early warning, water management, and city-wide adaptation planning. These interventions will be explored with the Chinese context in mind, and in Section 4 we will develop policy recommendations.

3. Potential Digital Solutions for Climate Change Adaptation: Two Case Studies

A wealth of scholarly literature has thoroughly explored the prospective contributions that digital technologies could offer in bolstering climate change adaptation [6]. These technological instruments serve a dual role – they facilitate long-term strategizing for adapting to climate change and provide support in predicting and responding to immediate climate-induced threats. Here, I scrutinize two globally implemented digital interventions within this section. The first one concentrates on climate change monitoring and the development of early warning systems. The second intervention focuses on urban water management, specifically crafted to mitigate the impacts of flooding – the most frequently encountered immediate climate hazard in China. Both of these digital tools exemplify the potential of technology in facilitating adaptive measures and proactive responses to the dynamic climate landscape.

3.1. AI techniques for high accuracy precipitation forecasting

Climate change monitoring and related hazards early warning are the first step in climate change adaptation. The foundation of effective early warning systems relies on precise forecasting of climate and weather extremes. China has made substantial efforts and progress in developing and implementing weather extreme forecasting systems (Figure A2). Current weather forecasting approach relies on physics-based techniques. Such methods are sensitive to approximations of the physical laws on which they are based and are constrained by their high computational requirements [7]. The efficiency and accuracy of the weather forecast system should therefore be further improved [3]. For instance, China Meteorological Administration have issued the Meteorological Technology Development Leading Program 2020–2035 for promoting meteorological modernization through develop and deploy smart technologies [8].

---

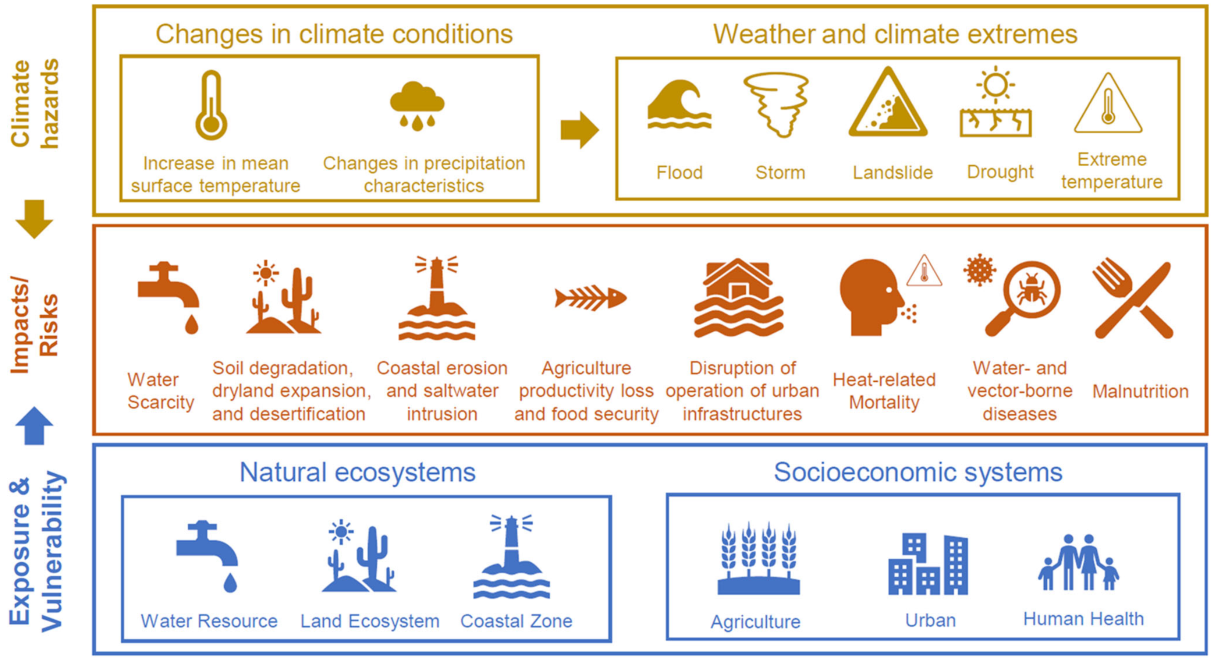
[1] In the context of climate change, risks can arise from potential impacts of climate change as well as human responses to climate change. Related concepts to these two types of risk are "physical risk" and "transition risk." The risks (including its components: hazards, exposure, and vulnerability) discussed in this chapter only refer to the former.

[2] **Climate-related hazard**: the potential occurrence of a natural trend or event that may cause loss of life, injury, or other health impacts, as well as damage and loss to property, infrastructure, livelihoods, service provision, ecosystems, and environmental resources. **Exposure**: the presence of people; livelihoods; species or ecosystems; environmental functions, services, and resources; infrastructure; or economic, social, or cultural assets in places and settings that could be adversely affected. **Vulnerability**: the propensity or predisposition to be adversely affected. Vulnerability encompasses a variety of concepts and elements including sensitivity or susceptibility to harm and lack of capacity to cope and adapt.

[3] EM-DAT stands for Emergency Events Database. It is an international database that contains comprehensive information on natural and technological disasters that have occurred around the world since 1900.

[4] Flood includes riverine, flash, and coastal flood; storm includes tropical cyclone and convective storm; extreme temperature includes heat and cold extremes and severe winter conditions.

Figure 1
Major climate change risks facing China



A promising new approach for precise precipitation forecasting is currently in development, utilizing AI techniques [9]. Unlike traditional methods that rely on explicit physical laws, AI weather forecast models learn to predict weather patterns directly from observed data, resulting in faster and more accurate predictions [7]. These approaches, which include Google's MetNet2, Pangu-weather, and others, also have the potential to improve the scope and resolution of the predicted forecasts [10].

Although it is still in the laboratory stage, MetNet-2 has shown its potential for accurate and efficient precipitation forecasting [9]. The prediction performance and speed of MetNet-2 exceed those of traditional physics-based models, especially for nowcasting (i.e., predicting weather between 2 and 6 h ahead). Compared to physics-based models, MetNet-2 outperforms the state-of-the-art High Resolution Ensemble Forecast model [11] for weather forecasts up to 12 h ahead. Meanwhile, the computational requirements of an AI-based approach are smaller and the speed is faster. Comparing prediction times, physics-based models take ~1 h, whereas MetNet-2 takes ~1 s [7]. By incorporating AI techniques for precipitation forecasting, we can achieve a new modeling paradigm for weather prediction that boasts remarkable accuracy. This cutting-edge approach eliminates the need for manual coding of weather physics and instead utilizes end-to-end learning from observations to weather targets. Additionally, the AI technology allows for parallel forecasting on low-precision hardware. This represents a significant advancement in weather prediction methodology.

It is notable that these models have only recently been published in journals such as Nature Communications and have not yet been implemented. Several obstacles hinder the implementation of such approaches. The first is that the technologies need to be further developed to expand the scope of weather phenomena considered and extend the forecasting horizon to days and weeks, but there is no clear mechanisms and incentives for multiple participation of universities and corporate research institutes in China. For instance, according to the Meteorological Law of the People's Republic of China, some weather detection data must be kept confidential [12]. This may affect the data availability for research on new technologies from private institutions. Also, while there are incentives for innovation within the meteorological department, there are no clear channels and incentives for external participation in innovation. The second is that they are more data intensive, and this creates issues with regard to data collection, integration, and governance [7]. The performance of MetNet-2 heavily relies on the quality and quantity of data used for training. Thus, obtaining accurate and reliable weather data from various sources can be challenging, especially in areas with limited weather stations.

3.2. Operational digital twins in the urban water sector

Changes in the spatiotemporal distribution of precipitation driven by climate change create challenges for water management in Chinese urban areas. The substantial uncertainty associated with precipitation events results in increased frequency of high flows within sewer systems, causing a significant number of sewer overflows. These overflows discharge untreated wastewater into the environment, posing a serious threat to environment [13]. This exacerbates water pollution, the risk of water scarcity, and water-borne disease [14]. The Swedish cities of Gothenburg and Helsingborg have implemented a digital twin approach to water resource management [13], which has great potential to reduce the vulnerability of Chinese urban water sector to climate change.

The digital twin approach implements a decision support system with online flow prediction and suggestions for control strategies. Utilizing the digital twin approach provides greater confidence in decision-making by enabling quick visualization of the effects of changes in control strategy [13]. Simulation results indicate that implementing real-time control strategies can significantly reduce sewer overflow events in the Gothenburg case, with potential benefits including more stable water treatment processes, lower risk of critical load situations, and increased flexibility for handling issues with accumulation of material.

Sewer overflows are common in Chinese cities after heavy rainfall [15]. The untreated wastewater, possibly carrying pollutants from the ground, enters the urban environment, causing serious water pollution, freshwater shortages, and an increase in water-borne diseases [14]. Such a climate change vulnerability has not been well addressed in China. This vulnerability will be magnified in a future of rapid urbanization and increasing climate hazards. Applying digital twin solutions in urban water management therefore is feasible and has great potential in China.

While, drawing on experiences from the Gothenburg and Helsingborg cases, implementing the digital twin approach presents several challenges [13]. The major challenge is integrating data reflecting water flow fluctuations from multiple sources, including weather forecasting, water-intensive entities, and sewage treatment sector. Insufficiency of high-quality data collection and management, lack of inter-institutional data transfer coordination mechanisms, or absence of privacy protection laws could prevent a smooth integration of multiple source data. Another challenge is to establish trust and confidence in the digital twin system among control room operators.

4. Governance Innovation for Leveraging Digital Adaptation

As demonstrated in the case studies above, digitalization can play a significant role in promoting climate change adaptation. Meanwhile, there are also many challenges to develop and deploy such digital tools. From the above case studies, these challenges could be summarized into four categories: (a) the development of digital technologies, especially research that promotes techniques from the laboratory stage to practical application; (b) technical issues to data collection, management, and integration; and (c) coordination issues between multiple institutions.

Considering that climate adaptation often has externalities, corresponding incentive policies are needed to alleviate market failures and encourage the development of digital technologies for climate change adaptation. China has corresponding research and development support for climate change adaptation. For example, the Ministry of Science and Technology's key research and development program supports the study of extreme weather and forecasting technologies, as well as the research of climate change adaptation decision support systems. However, such research is only carried out on a small scale in universities and other research institutions. Meanwhile, the results of such research often remain in the laboratory stage and the last mile problem of actual application has not been solved. In addition, many technologies are often controlled by private sectors, such as advanced AI technologies. Currently, there is a lack of broader incentive policies to promote the participation of multiple sectors in development of digital solutions for climate adaptation.

The application of digital technology for climate change adaptation requires support from multiple sources of data. The government aims to promote data sharing by setting big data standards, establishing data element markets, and other means. However, there are still several issues with climate change data, including missing data such as uneven distribution of meteorological stations and the lack of meteorological data in some areas, poor data quality, insufficient data sharing, inadequate data standardization, and a lack of standardized sharing methods and policies. Additionally, privacy and data security cannot be guaranteed, which undermines the willingness of individuals and businesses to share data.

The application of digital technology for climate change adaptation requires coordinated efforts from multiple sectors, including central and local governments, public and private sectors, and coordination between industries. China is actively establishing cross-sectoral coordination mechanisms for climate change adaptation, promoting the coordinated advancement of policies and technologies. For example, 17 departments jointly released the National Climate Change Adaptation Strategy for 2035. However, the substantive coordination mechanism is still in its early stages of development and is not yet fully established.

Under this context, I finally develop following three policy recommendations for leveraging digitalization to promote climate change adaptation in China.

1) Strengthen the support of scientific and technological innovation, and formulate more resilient and targeted adaptation solutions. Comprehensively evaluate the scientific, technological, economic, and social research results related to China's adaptation to climate change, start with digital adaptation in agriculture, cities and ecology, and systematically strengthen the application of digital technologies in agricultural production, urban disaster prevention and mitigation, and ecological protection. What needs special attention is that the government should provide support for the research on the implementation of digital technology. This includes providing data and policy support for universities and research institutions in the private sector, and promoting the connection between research institutions and practical application sectors.
2) Develop big data standards, data-sharing mechanisms, and regulation policies, including especially (1) creating data-sharing centers (data marketplace) that bridge the data gap between different digital projects, and (2) developing appropriate data regulation policies/laws to remove disincentives for data-sharing (e.g., privacy policies, justice).
3) Exploring mechanisms for pluralistic social participation to allow groups at all levels of society to participate in with effective coordination mechanisms to implement climate adaptation solutions effectively. Through the active guidance of the government, the government publishes scientific facts and impact reports on climate change through official channels, and encourages public sector and state-owned enterprise (SOE) to design action plans for adaptation to climate change in advance. Deploy themed practical activities related to climate adaptation, widely mobilize the whole society to participate in climate adaptation, and promote the formation of a social atmosphere in which everyone cares, supports and participates in climate change adaptation.

Acknowledgments

The author acknowledges the constructive comment from Eric White and Qiuping Li from the World Economic Forum and Chaofeng Shao from Nankai University.

Funding Support

This article is one of the outputs of the China Council for International Cooperation on Environment and Development

(CCICED) Special Policy Study "Promoting Digitalization and Green Technologies for Sustainable Development."

Conflicts of Interest

Daoping Wang is an Editorial Board Member for *Green and Low-Carbon Economy*, and was not involved in the editorial review or the decision to publish this article. The author declares that he has no conflicts of interest to this work.

Data Availability Statement

Data are available from the corresponding author upon reasonable request.

Author Contribution Statement

Daoping Wang: Conceptualization, Methodology, Software, Validation, Formal analysis, Investigation, Resources, Data curation, Writing – original draft, Writing – review & editing, Visualization, Supervision, Project administration, Funding acquisition.

References

[1] Intergovernmental Panel on Climate Change. (2023). *Climate change 2021 – The physical science basis: Working Group I Contribution to the sixth assessment report of the intergovernmental panel on climate change*. UK: Cambridge University Press. https://doi.org/10.1017/9781009157896

[2] World Bank Group, & Asian Development Bank. (2021). *Climate risk country profile: China*. https://www.adb.org/sites/default/files/publication/703641/climate-risk-country-profile-china.pdf

[3] Ministry of Ecology and Environment of the People's Republic of China. (2022). *Guójiā shìyìng qìhòu biànhuà zhànlüè 2035* [National climate change adaptation strategy 2035]. https://www.mee.gov.cn/xxgk2018/xxgk/xxgk03/202206/W020220613636562919192.pdf

[4] United Nations Framework Convention on Climate Change. (2018). *The People's Republic of China third national communication on climate change*. https://unfccc.int/sites/default/files/resource/China%203NC_English_0.pdf

[5] World Bank Group. (2023). *Climate change overview: Country summary*. https://climateknowledgeportal.worldbank.org/country/china

[6] Argyroudis, S. A., Mitoulis, S. A., Chatzi, E., Baker, J. W., Brilakis, I., Gkoumas, K., . . . , & Linkov, I. (2022). Digital technologies can enhance climate resilience of critical infrastructure. *Climate Risk Management*, *35*, 100387. https://doi.org/10.1016/j.crm.2021.100387

[7] Kalchbrenner, N., & Espeholt, L. (2021). MetNet-2: Deep learning for 12-hour precipitation forecasting. *Google Research*. https://ai.googleblog.com/2021/11/metnet-2-deep-learning-for-12-hour.html

[8] The State Council of the People's Republic of China. (2019). *Qìxiàng guāncè jìshù fāzhǎn yǐnlǐng jìhuà (2020–2035 nián)* [Meteorological technology development leading program (2020–2035)]. http://www.gov.cn/zhengce/zhengceku/2019-11/04/5456909/files/c7c2e1cfb36d4817ba6f6d8fd293f7f7.pdf

[9] Espeholt, L., Agrawal, S., Sønderby, C., Kumar, M., Heek, J., Bromberg, C., . . . , & Kalchbrenner, N. (2022). Deep learning for twelve hour precipitation forecasts. *Nature Communications*, *13*(1), 5145. https://doi.org/10.1038/s41467-022-32483-x

[10] Bi, K., Xie, L., Zhang, H., Chen, X., Gu, X., & Tian, Q. (2022). *Pangu-Weather: A 3D high-resolution model for fast and accurate global weather forecast*. arXiv. https://doi.org/10.48550/arXiv.2211.02556

[11] National Weather Service. (2023). *High Resolution Ensemble Forecast system undergoes upgrades*. https://www.weather.gov/news/211205-href-model-upgrade

[12] Ministry of Ecology and Environment of the People's Republic of China. (1999). *Meteorology Law of the People's Republic of China*. https://english.mee.gov.cn/Resources/laws/envir_elatedlaws/200710/t20071009_109959.shtml

[13] Valverde-Pérez, B., Johnson, B., Wärff, C., Lumley, D., Torfs, E., Nopens, I., & Townley, L. (2021). *Digital water: Operational digital twins in the urban water sector: Case studies*. International Water Association. https://iwa-network.org/publications/operational-digital-twins-in-the-urban-water-sector-case-studies/

[14] UIC Today. (2015). *Combined sewer systems lead to risk of illness after heavy rains*. https://today.uic.edu/combined-sewer-systems-lead-to-risk-of-illness-after-heavy-rains/

[15] Talamini, G., Shao, D., Su, X., Guo, X., & Ji, X. (2017). Combined sewer overflow in Shenzhen, China: The case study of Dasha River. *WIT Transactions on Ecology and the Environment*, *210*, 785–796. https://doi.org/10.2495/SDP160661

[16] Ying, L., & Guofu, W. (2022). Qìxiàng zāihài fēngxiǎn guǎnlǐ xìtǒng shèjì yǔ yìngyòng [Design and implementation of meteorological disaster risk management system]. *Journal of Applied Meteorological Science*, *33*(5), 628–640. http://doi.org/10.11898/1001-7313.20220510

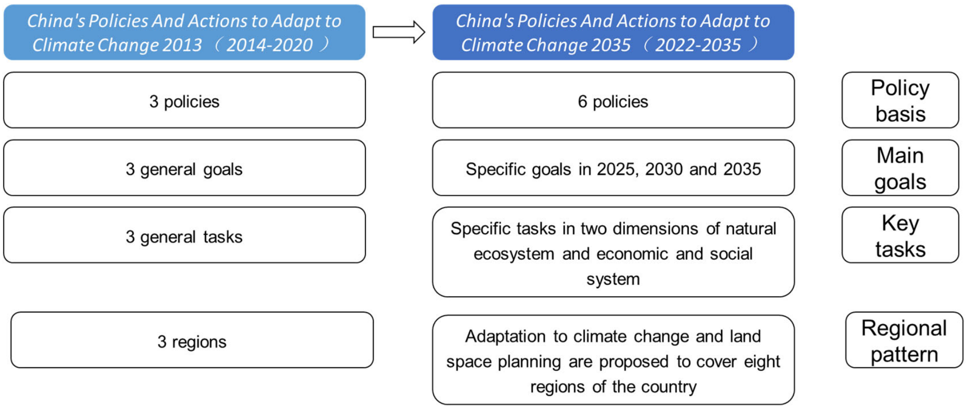
How to Cite: Wang, D. (2026). Digitalization and Climate Change Adaptation in China. *Green and Low-Carbon Economy*, *4*(1), 129–135. https://doi.org/10.47852/bonviewGLCE32021306

Appendix

Chinese Policy Box | China's Policies and Actions to Adapt to Climate Change

Since 2013, China has released two versions of the *China's Policies and Actions to Adapt to Climate Change*. The latest version (2022–2035) focuses on strengthening climate change monitoring, early warning, and risk management, including: improving the climate change observation network, strengthening climate change monitoring, prediction and early warning, strengthening climate change impact and risk assessment, and strengthening comprehensive disaster prevention and mitigation.

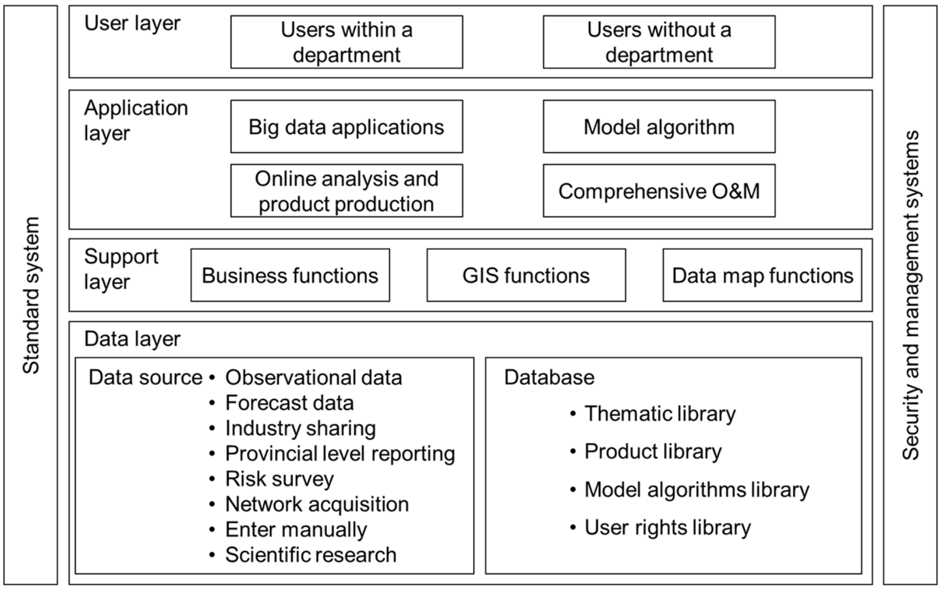
Figure A1
Chinese climate change adaptation strategy



Chinese Case Box | China Meteorological Disaster Risk Management System

In order to improve the support capacity of disaster risk management, China has initially formed a set of technical systems consisting of meteorological disaster risk survey, scientific determination of disaster-causing value, disaster risk early warning based on value, quantitative disaster risk assessment, refined disaster risk zoning, business inspection and benefit evaluation, and initially established a four-level meteorological disaster risk management business system at the national, provincial, municipal, and county levels [16].

Figure A2
Framework of meteorological disaster risk management system



At present, the system realizes real-time release of disaster monitoring, disaster event identification, impact assessment, risk assessment, risk estimation, risk zoning, and other types of business products, and the application in national meteorological business departments showsthat the system has good business capabilities and development prospects.