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Constructing an Open Science Action Roadmap to Seize Development Opportunities: Post-Prints

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Abstract

Open science has achieved global consensus, and global open science governance requires China' s participation. To seize development opportunities, this article investigates and analyzes the development trends of global open science and their impact on the scientific community. Based on case studies of China' s open science practices, it elaborates on the current status and challenges of open science development in China. Accordingly, it designs a roadmap for open science in China, with open research infrastructure and open science policies as key drivers, and proposes recommendations for advancing open science development in China.

Full Text

Building a Roadmap for Open Science Action: Seizing Global Development Opportunities

Preamble

Special Issue: Open Science Development Trends and Governance Strategies

UNESCO' s requirements for open science governance have gained universal recognition. In December 2021, the revised *Law of the People's Republic of China on Science and Technology Progress* explicitly identified promoting open science as a development goal. To comprehensively understand global open science development trends and formulate China' s open science governance strategies, the Chinese Academy of Sciences established a key consulting project titled "Research on the Situation and Impact of Open Science" in May 2022. Under the guidance and support of the Bureau of Academic Divisions of the Chinese Academy of Sciences, and based on the project's main report and special research reports combined with current practices in China' s open science development,

the *Bulletin of the Chinese Academy of Sciences* has organized this special issue on "Open Science Development Trends and Governance Strategies" to propose roadmaps and policy recommendations for open science, advance China' s open science process, and seize global open science development opportunities.

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Open science has reached a global consensus, and global open science governance requires China' s participation. To seize development opportunities, this article investigates and analyzes global open science development trends and their impact on the scientific community. Based on practical cases of open science in China, we elaborate on the current status and challenges of open science development in China. Accordingly, we design a roadmap for China' s open science, with open research infrastructure and open science policies as key drivers, and propose recommendations for advancing China' s open science development.

Keywords: open science, global situation, open science roadmap, open research infrastructure, open science policy

Openness is one of the essential attributes of science, and open science has accompanied modern science since its inception [1]. At the end of the 16th century, modern science began to sprout, and the emergence of scientific journals in the 17th century drove the first scientific openness transformation. In the late 20th century, a journal pricing crisis emerged in the academic community, leading to the proposal of the open access (OA) concept for scientific and technological information [2]. In 2003, the first Berlin International Conference on Open Access released the milestone *Berlin Declaration on Open Access to Knowledge in the Sciences and Humanities* (hereinafter referred to as the *Berlin Declaration*) . In 2015, scientific data sharing initiatives emerged [3]. During the global COVID-19 pandemic that broke out at the end of 2019, the proportion of OA scientific information related to COVID-19 reached 82%, strongly supporting global COVID-19 vaccine and drug research and enabling the global scientific community to recognize open science as a future research paradigm that accelerates scientific research. The progress of open science received a crucial push in 2021 when 193 UNESCO member states approved the *UNESCO Recommendation on Open Science* [4], forming a wave of global open science governance.

Global Development Trends and Impact of Open Science

Global Development Trends of Open Science (1) Open access has become the mechanism for transforming scientific research into open science. Initially, open access only applied to publications, but today it applies to the entire research process to establish an open mechanism for knowl-

edge [5], effectively transforming scientific research outputs funded by public investment into drivers of social innovation development capacity [6]. Multiple open access models coexist globally, including the EU' s "Read & Publish" open transformation model led by the "cOAlition S" alliance, India' s "One Nation, One Subscription" model negotiated by library consortia, and the U.S. White House' s "Public Access" model requiring government-funded research results to be publicly accessible. As data becomes a foundational resource for scientific and technological innovation, the UK has adopted an open science mechanism focused on intelligent data open access, and this concept of returning to the essence of science has become a trend [5]. A country' s degree of open access may affect its entire open science process. The Netherlands proposed a national open science plan in 2017, and France proposed its second national open science plan in 2021, both announcing the achievement of 100% open access to publications by 2020 and 2030, respectively. In the 2022 U.S. White House open access memorandum, federal agencies were required to provide public access to federally funded research publications and their supporting data no later than the end of 2025. This sudden acceleration of policy will have a major impact on the global publishing ecosystem [7].

(2) Open data infrastructure construction is accelerating the transformation of scientific research paradigms. Scientific data has become a strategic resource, and scientific data open sharing has been widely incorporated into science and technology policy systems. In February 2022, the European Commission announced a new generation of data governance legislation, the *Data Act* [8] draft, involving provisions on data sharing, public institution access, international data transfer, cloud switching, and interoperability. Secondary innovation based on open data infrastructure has become a future trend in research organization models. In 2021, the U.S. National Science and Technology Council released the *Strategic Overview of National Research and Development Facilities* [9], redefining the constituent elements of major facilities with scientific data as the core. To address privacy and security issues in data resource openness and utilization, governance of research information assets led by research infrastructure is becoming a solution. In 2021, the U.S. National Science Foundation (NSF) released the *Research Infrastructure Guide* [10], proposing to inventory the "information assets" of research infrastructure, establish an "information assets" inventory, and identify and manage critical information assets under the guidance of the "Open Science Cyber Risk Profile" (OSCRP) project according to their value, sensitivity, and classification.

(3) A global open and inclusive multi-stakeholder governance structure is taking shape. The open and inclusive content emphasized in UNESCO' s *Recommendation on Open Science* is leading and will continue to lead the future development trend of open science governance. The transparency of the entire scientific research process has become a new governance goal. Preregistration and registered reports are considered two promising open science practices that provide transparency in scientific processes [11]. The neuroimaging community is adopting open data repositories and open laboratory note-

books to ensure reproducible research [12]. Research infrastructure has become an object of open and inclusive governance. In 2021, UK Research and Innovation (UKRI) announced an initial investment of £50 million to carry out the construction and upgrading of 17 research infrastructure projects [13]. In 2022, the NSF announced the establishment of the Environmental Data Science Innovation and Inclusion Lab to achieve diversification of environmental data by making inclusivity a core value. Open science policy has become an important governance tool. In 2022, UNESCO proposed that "open science policy is an accelerator for achieving sustainable development goals"[14]. European national open science policies are usually related to three dimensions: "open input, open process, and open output," with most countries adopting a protectionist policy on "open output" [15]. The U.S. White House designated 2023 as the Year of Open Science [16], announcing the provision of new funding, improvement of research infrastructure, expansion of research participation for emerging scholars, and increased opportunities for public participation.

Impact of Open Science on Scientific Research (1) Open science is changing research paradigms and improving the innovation efficiency of the entire scientific system. Thomas Kuhn [17] pointed out that a research paradigm refers to recognized scientific achievements that, during a specific historical period, provide models, problems, and solutions (exemplars) for members of the scientific community, enabling adherents to break away from other competing models of scientific activity. Yang Wei [18] proposed a four-quadrant model of open and inclusive governance for scientific research and a value model centered on the knowledge innovation chain, describing several dynamic directions in the development process of open data subjects in the knowledge innovation chain. Key issue domains for global open science may include resource-intensive openness, high costs of OA article processing charges (APCs), and practices by funders and research institutions to promote open research implementation [19]. Open science is becoming a strategy. In open drug development for malaria and tropical diseases, openness is considered a more effective and ethical way to conduct biomedical research [20]; open science has become a tool, and the FAIR data principles provide excellent guidance for improving the quality and efficiency of research and innovation systems; open science has become a methodology. Global research infrastructures such as the EU' s Open Access Infrastructure Research Project (OpenAIRE) and European Open Science Cloud (EOSC), and the U.S. Center for Open Science' s Open Science Framework (OSF) have hosted scientific research projects from multiple countries and have become new mechanisms for research organization [21].

(2) Open science promotes responsible research in academia and improves the reliability of scientific research. Under open science, the transparent research process promotes researchers to conduct responsible research. Open science has become an intrinsic "trust mechanism" for academic exchange, and the public verification of academic achievements improves the robustness of the scientific system. The academic community has promoted many practices

that adopt open science to conduct responsible research and alleviate the reproducibility crisis in scientific research. For example, the academic community' s self-organized academic exchange preprint platform arXiv and pre-registration platforms open original data and materials at the time of submission, encouraging researchers to report content crucial for reproducible research [22]; in 2014, the Committee on Publication Ethics (COPE) composed of psychology scholars proposed measuring the transparency procedures of academic journals from eight aspects [23].

(3) Open science is promoting a global science model, making scientific research more equitable and inclusive. Open science makes the boundaries of the academic community increasingly blurred, and science becomes more inclusive and equitable. This is specifically reflected in: Inclusivity and equity for the identities of participating entities, which includes not only cross-disciplinary, cross-institutional, and cross-regional cooperation and knowledge sharing within the scientific research system but also participation and sharing between the scientific research system and different stakeholders, even non-scientific research systems; Inclusivity and equity in the degree of participation in scientific activities, where any entity can assume various competent roles in the scientific research process. To achieve the above equity to a certain extent, a "global mindset" is still needed to ensure systematic and effective transformative approaches are adopted globally [24].

Current Situation and Challenges of Open Science Development in China

Development and Practice Status of Open Science in China In 2004, the Chinese Academy of Sciences and the National Natural Science Foundation of China signed the *Berlin Declaration on Open Access*, marking China' s participation in the global open access movement. In 2014, the Chinese Academy of Sciences and the National Natural Science Foundation of China respectively issued open access policy statements encouraging open access to research papers funded by public finance. In 2021, China signed UNESCO' s *Recommendation on Open Science*. According to SCIE (Science Citation Index Expanded) data, China has become the country with the largest number of OA papers published globally since 2019, with its publication volume accounting for approximately 1/4 of the global total OA papers. According to 10-year data (2012–2021) from the Dimensions platform, China ranks second globally in the number of scientific datasets published. China has become a major contributor to open science.

Based on 149 open science-related practice cases (since 2002) collected from China' s scientific community by the project team in October 2022, we analyzed the current practice status of open science in China.

2.1.1 China's research-driven open science innovation practices. When the practice cases are categorized by three themes– "open access," "open data," and "open science governance" –we find that China' s open science data actions

are relatively limited: "open access" cases account for 35%, focusing on the open sharing of scientific and technological achievements, building knowledge repositories and open publishing platforms, with participants involving libraries, research funding agencies, journals, and publishers; "open data" cases account for 20%, focusing on scientific data storage and openness, building data platforms and formulating data management policies, with participants involving governments, research institutions, universities, and enterprises; "open science governance" cases account for 45%, focusing on building consensus and influence for open science, creating infrastructure and cultivating social culture, with participants involving governments, research institutions, research funding agencies, universities, science and technology alliance organizations, and social organizations.

Further analysis of the research models contained in the above practice cases reveals that current scientific research in China mainly exists in two scientific research quadrants characterized by public publication [18]—organized research (high inclusivity and low openness) and global science (high openness and high inclusivity). In the organized research model, Chinese researchers have become accustomed to submitting research results to OA journals and participating in open exchanges through preprints. In the global science model, new research flows are forming with important links including "domain alliance organizations, resource open sharing, large scientific instrument platform openness, data platform construction, innovative product generation, and collective influence enhancement." A notable case is the "Earth Big Data Science Engineering" project, which has established an earth science big data sharing platform to promote earth science big data sharing, advance earth science research and socio-economic construction, build a smart earth, and support the UN Sustainable Development Goals (SDGs). The proportion of "global science" cases reaches 88%, which may be the future trend of China's research model.

2.1.2 Comparison of China's open science practices with UNESCO's open science actions. UNESCO's *Recommendation on Open Science* proposes seven action areas. This study compared 52 specific actions in these seven areas with China's open science practices, finding that China's open science practices have covered all seven areas. Especially in 2021 and 2022, China actively promoted consensus and consultation on open science. The CAST UN Consultative Committee on Open Science and Global Partnership was established, and the China Association for Science and Technology published the *Blue Book of China's Science and Technology Journals Development (2021)* with the theme "Academic Publishing in an Open Science Environment" and the *China Open Access Publishing Development Report (2022)*. The comparison also revealed imbalances in China's actions across the seven areas. For example, there are insufficient cases for actions such as cultivating an open science culture and promoting open science innovation methods. Practices in multiple action areas are discontinuous, specifically manifested by long blank periods in exploring diversified open science paths, creating an open science policy environment, coordinating open science incentive measures, and investing in open

science human resources and capacity building.

2.1.3 China' s open science maturity in the current global research ecosystem. Yang Wei et al. proposed an Open Science Maturity Index (OSRI) to measure the temporal progress of open science in different countries or regions worldwide . The OSRI indicator system describes the maturity of open access, open data, and open policies, covering indicators such as academic paper output, academic influence, large scientific facilities and major scientific instrument platforms, scientific and technological journals published by China, data platforms, policy systems, and policy influence. In 2021, the global OSRI ranking was EU27, USA, UK, China, Germany, Japan, STLCs , Russia, and India (Figure 1 [Figure 1: see original paper]). In terms of OA maturity, the EU27 has the largest OA paper volume and international cooperation volume due to group effects. In terms of open data maturity, the USA and EU27 are far ahead due to their advantages in shareable data volume and data quality, while China currently ranks third, mainly benefiting from rapid growth in three aspects: shareable data, purchasing power, and academic quality of data. China has not yet issued a national open science policy, while data powers or publishing powers such as the USA, UK, Germany, and the Netherlands have significantly higher open science policy maturity.

To further improve open science maturity, China needs to make improvements in three aspects: Increase the share and volume of open access and international cooperation academic output; Enhance the scientific research quality, information quality, and reliability quality of shareable data, and conduct capacity building in legal, infrastructure, and financial aspects for accessible data; Participate in global open science governance and continuously enhance the competitiveness of national open policies.

Challenges for China' s Open Science Actions (1) China' s substantive participation in global open science is insufficient, and consensus on open science goals has not yet been reached. The EU ensures that European scientists fully benefit from data-driven science, Canada hopes that open science can maximize benefits for national well-being, and the USA defines open science as "the principle and practice of making research outputs and processes available to all, while respecting diverse cultures, maintaining security and privacy, and promoting collaboration, reproducibility, and equity." Under the definition of "open science" in the *Recommendation on Open Science*, China has not yet clarified its open science goals. Open science practice in China suffers from severe isolation, and unified national-level actions need to be established. Current global open science governance needs China, and China should actively promote the development process of open science, propose China' s open science routes and action plans, and provide examples for global scientific research.

(2) China' s open access faces barriers, and open science mechanisms are insufficient. China' s open access faces three thresholds, including "who is the driving entity," "how to gradually bridge the price gap," and "how to sta-

bilize the development of China' s publishing scientific journals" [1]. China has not mandated open access to scientific research results, but the number of OA papers published by Chinese corresponding authors has increased year by year. According to the *2022 Global OA Journals and APC Monitoring Report* released by the National Science Library of the Chinese Academy of Sciences, China' s OA publication volume in 2022 was approximately 270,000 papers, with an annual growth rate of 44%. China' s open access costs have not yet been clarified. In 2021, China' s expenditure on obtaining publication data was approximately RMB 12 billion, including about RMB 9 billion for library literature procurement and RMB 2.9 billion paid by Chinese corresponding authors for APCs , while there was a 2.5-fold difference between the global average APC price in 2021 and the APC cost price . China has not yet clarified the open conversion method for literature procurement expenses. China' s scientific journals adopt a wait-and-see attitude toward OA publishing, preprints, and data repository construction. Coupled with the "lack of core technology"in China's scientific journal open publishing technology, it is difficult to support Chinese authors' publication needs. In 2021, 90% of OA papers by Chinese authors were published in foreign journals. As China is already a major country in global paper and OA paper publication, it has the responsibility to promote the open sharing of trustworthy scientific research results. Through collective efforts by research funding agencies, library consortia, and other entities, China should conduct global data group purchase negotiations, establish reasonable APC expenditures in China' s research funds, and achieve rationalized conversion between APC expenditures and literature procurement expenses.

(3) China' s infrastructure supporting intelligent data-driven research is insufficient, making it difficult to build a global scientific and technological innovation cooperation platform. According to incomplete statistics, by 2007 China had built 5,000–6,000 scientific databases of varying scales and quality [25]. However, China still faces enormous challenges in promoting data reuse, facilitating scientific research innovation, and promoting social open innovation: the consistency of syntax, structure, and semantics for various types of scientific data is insufficient; interconnectivity among various types of data centers, repositories, and platforms is inadequate, and a national data infrastructure has not yet been formed; the service efficiency of scientific data infrastructure is insufficient; hierarchical and categorized scientific data open policies have not been clarified; intellectual property confirmation mechanisms have not been clearly explored; and incentives for data producers to actively submit high-quality scientific data are lacking. There is an urgent need to establish a national-level open science data center and achieve integrated construction of scientific data infrastructure.

(4) China's open science governance capacity is insufficient to support the open science development environment. China has not yet formulated and issued policies specifically targeting "open science,"and existing open science-related policies are relatively fragmented. Since the "Eleventh Five-Year Plan," China has strengthened the construction of basic scientific and technological

innovation capabilities, but has focused on research result management while neglecting "research process" management. Since 2021, China has strengthened and improved evaluation and incentive mechanisms, explored the establishment of dynamic monitoring and third-party evaluation, explored long-cycle evaluation for basic research, and improved academic evaluation mechanisms for homogenization and equivalent evaluation of domestic and international journals and classified evaluation of scientific and technological journals. However, actions in formulating national-level regulations and systems, innovating public service environments, and promoting practices in research institutions are weak. Under the global open science consensus, China' s participation in global open science governance will enter an unprecedented period of development opportunities, and there is a need to form a complete open science policy system and sustainable development model.

China' s Open Science Roadmap and Implementation Actions

Design of China' s Open Science Roadmap Addressing the gaps and current challenges between China' s open science status and international development trends, and based on Maslow' s hierarchy of needs theory [26], we adopt a roadmap approach (Figure 2 [Figure 2: see original paper]) to plan and clarify China' s open science goals, measures, and medium- to long-term development routes.

China' s open science roadmap is planned across five levels:

(1) Survival needs. This level corresponds to ensuring that China can establish a foothold in the international open science environment. Survival needs are reflected in three aspects: Academic self-reliance in the world academic community, becoming an indispensable soil for world academic contributions, with representative indicators being: academic output is commensurate with China' s world share of population or researchers; academic influence is not lower than the world average; and large-scale scientific instruments and major scientific device platforms that are irreplaceable worldwide and available to scientists from multiple countries begin to appear. Visibility on scientific communication platforms, with representative indicators being: scientific and technological journals published by China enter world scientific data platforms on a large scale; and data platform plans with the capacity to accommodate scientific data from various countries are launched. Adaptability in science policy, with representative indicators being: the policy system adapts to the policy requirements of the *Recommendation on Open Science*; and policy influence receives global attention. China has already achieved the requirements of this level.

(2) Safety needs. This level corresponds to ensuring that Chinese scientists can obtain stable, secure, orderly, and uninterrupted data access and data service protection, and can safely reside in the international open science environment. Safety needs are reflected in three aspects: Academic self-strengthening

in the world academic community, having become a significant part of world academic contributions that cannot be ignored, with representative indicators being: academic output is not lower than 20% of the world, roughly equivalent to the USA or EU; academic influence is higher than the world average; and several unique large-scale scientific instruments and major scientific device platforms are built. Prominence on scientific communication platforms, with representative indicators being: scientific and technological journals published by China occupy about 5% of world scientific data platform data volume, forming machine language translation capabilities; and representative data platforms with global prominence are formed. Legal security in science policy, with representative indicators being: basic international legal and contractual guarantees for data security can be provided; and policies with global bargaining power are formed. It is expected that all requirements of this level will be achieved by 2025.

(3) Social needs. This level corresponds to Chinese scientists being able to effectively integrate into the international open science environment and become a respected force in the international open science community. Social needs are reflected in three aspects: Social status in academia, with representative indicators being: academic output has formed an indispensable pole of world academic output; international influence indicators such as FWCI (Field-Weighted Citation Impact) and highly cited scholars are close to the levels of the USA or EU; and China has become an indispensable component of international large-scale scientific instruments and major scientific device platforms. Social status on scientific communication platforms, with representative indicators being: scientific and technological journals published by China occupy a place in world scientific data; and competitive data platforms are formed. Social status in science policy, with representative indicators being: a policy system that can be integrated into global open science governance is formed; and policies with global influence are formed. China should strive to achieve all requirements of this level by 2030.

(4) Esteem needs. This level corresponds to establishing China' s dignity, achievement, control, independence, status, and prestige in the international open science environment. Esteem needs are reflected in three aspects: Esteemed status in academia, with representative indicators being: academic output can run in parallel with the USA or EU; international influence indicators such as FWCI and highly cited scholars are comparable to the USA or EU; and a situation parallel to the USA and EU is formed in large-scale scientific instruments and major scientific device platforms. Respected status on scientific communication platforms, with representative indicators being: scientific and technological journals published by China are respected by global scientists in world scientific data; and data platforms originating from China have become an indispensable part of world data platforms. Social status in science policy, with representative indicators being: open science global governance policies commensurate with China' s status as a permanent member of the UN Security Council are contributed; and China becomes another pole of policy influence

with global impact besides the USA and Europe.

(5) Self-actualization needs. This level corresponds to China being able to drive its own development in the future and promote the overall development of international open science, becoming one of the leaders of the global knowledge community. Self-actualization needs are reflected in three aspects: Self-driven status in academia, with representative indicators being: a leading pole of world academic output is formed; international influence indicators such as FWCI and highly cited scholars lead the world; and China leads the development of international large-scale scientific instruments and major scientific device platforms. Self-driven status on scientific communication platforms, with representative indicators being: scientific and technological journals published by China become the core journal group of world scientific data; and China becomes a data platform powerhouse. Self-driven status in science policy, with representative indicators being: China leads global governance policies for open science; and China becomes a global policy driver. China is still far from the requirements of this level and should strive to achieve all requirements of this level between 2040 and 2050.

Open Research Infrastructure as the Driver of China' s Open Science Governance Open research infrastructure is an important object of open science governance. The open science infrastructure defined in the *Recommendation on Open Science* is a comprehensive infrastructure that supports open science and meets the needs of different communities, including virtual infrastructure and physical infrastructure. Based on China' s open science roadmap and drawing on the classification of the EU FOSTER project [27], we advance collaborative governance actions for five types of open science infrastructure in China (Figure 3 [Figure 3: see original paper]).

(1) Open access infrastructure supports the open sharing of scientific and technological resources through open publishing and open repositories, to break through the "paywall" barriers and intellectual property issues of open knowledge. Governance focuses on promoting the fullness of China' s OA papers: Issue national open access policies; Recommend reusable and well-functioning open access platforms and open publishing platforms; Upgrade institutional knowledge repositories that encounter development difficulties.

(2) Open data infrastructure supports the utilization and reuse of open big data, providing data supervision and open computing services. Governance focuses on the academic quality and information quality of China' s shareable data: Formulate national open data strategies or policies and open data incentive mechanisms; Upgrade existing platforms to build open data infrastructure, focusing on technology and service capabilities; Drive data privacy, security, and categorized openness governance based on infrastructure management.

(3) Open reproducible research infrastructure supports open workflows and open reproducible research testing. China does not yet have well-known

open reproducible research infrastructure. Governance focuses on the reliability quality of China' s shareable data: Encourage and guide the construction of experimental open platforms; Fully cooperate with China' s open-source communities; Encourage researchers to develop toolkits, software, and publish negative results that support open research.

(4) Open science evaluation infrastructure supports the evaluation of scientific research value. China has not yet incorporated open science into research evaluation. Governance focuses on adaptability in science policy: Establish scientific research performance evaluation mechanisms; Incorporate open science contributions into scientific and technical personnel career development evaluation and recruitment and promotion standards.

(5) Comprehensive open science infrastructure supports the implementation of open science clouds, large-scale scientific projects, and international large-scale scientific plans on a global scale. Governance focuses on enhancing national competitiveness: Issue China' s open science infrastructure construction plan; Jointly build by multiple stakeholders; Clarify the terms of use for infrastructure.

Open Science Policy as the Lever for China' s Open Science Actions China has both realistic and long-term needs for open science policies. In China's gradually "global science" model-oriented open science practice scenarios, there are needs for national policies and supporting policies for the governance of scientific and technological resource open access, data reuse governance, and innovation governance, as well as long-term policy needs oriented toward China' s open science infrastructure construction. These include national policies that can catalyze more innovation entities to participate and establish full research process services adapted to global scientific research, as well as supporting policies for continuous funding and innovation incentives. China' s open science policies need to form a relatively complete open science policy system and action strategy.

Designing China' s open science policy system and action framework. Incorporate China's open science policies into the category of scientific and technological innovation policies, while adapting to UNESCO' s open science policy action areas with 10 specific actions to design China's policy action advancement indicators: Establish hierarchical systems, from national policy formulation to coordination mechanisms for implementation by various participants; Promote multi-stakeholder practices, from the state to research institutions/organizations to carry out specific actions; Support innovative guarantees, establishing innovation mechanisms on the implementation path.

Establishing China' s open science policy action strategy. Clarify the entities involved in open science policies, and promote the participation of research institutions and universities—two key open science entities with currently weak practices—in open science practices as soon as possible. Formulate na-

tional open access policies, requiring public-funded scientific research results to provide public services and immediate open access, setting annual OA proportion targets, supporting policies, and implementation details. Strengthen the construction of institutional knowledge repositories. Construct an open data construction system, clarify the requirements and principles of open data infrastructure, establish mandatory data sharing measures in some key areas, and improve the value-added capacity and global innovation value of scientific data through top-level design and overall management.

Recommendations for Advancing China' s Open Science Development

(1) Reach consensus on China' s open science goals as soon as possible and advance through a roadmap approach. China' s open science should comply with the country' s political, administrative, and legal frameworks, be guided by the *Recommendation on Open Science*, respect diverse cultures, maintain security and privacy, promote international cooperation, reduce costs arising from research integrity and intellectual property issues, improve the relationship between science and society, and build a community with a shared future for mankind. China' s open science development should set short-term (2025), medium-term (2030), medium-to-long-term (2035), and long-term (2050) goals to address safety needs, social needs, esteem needs, and even self-actualization needs in China' s scientific and technological innovation. Using scientific research output, large scientific facilities, data centers, national policies, operating funds, and influence as China' s open science elements, we should carry out open science infrastructure governance.

(2) Advance open science through open access mechanisms and issue national open access policies. Clarify the opening of academic publications, open data, open-source software, source code, open hardware, open platforms, and identifiers and data specifications independently developed by China that are generated during China' s scientific and technological innovation process and funded by the government. Advocate for global open access, achieving 100% open access to China' s research output by 2025 (with 50% full-text open access). Formulate and issue national open access policies and supporting policies. Support the construction of knowledge repositories, support the construction of national open data centers, and provide public services and high-level international cooperation. Design management methods for open publishing and data management in research funding. Gradually increase the proportion of open access investment in R&D funds to ensure continuous investment in open research infrastructure construction and services.

(3) Formulate China' s open science action plan, with key entities performing their respective duties. Research funding agencies, libraries, and others should accelerate the compilation of data acquisition agreements, initiate negotiations and group purchases, and collaboratively pay data subscription fees and reasonable APCs to collaboratively build open access platforms. Domain data platforms, enterprise data centers, and others should build national open

data centers and drive data resource governance through infrastructure. Large scientific device platforms, research institutions, universities, and national laboratories should explore the construction of platforms or tools for open workflows and open reproducible research testing. Science and technology management departments and funding agencies should research science and technology evaluation systems and design open science evaluation indicators and incentive mechanisms for the research community. Multiple stakeholders should jointly build comprehensive open science infrastructure to support the global implementation of large-scale scientific projects and international large-scale scientific plans.

(4) Establish a multi-department joint working group to coordinate and advance overall work. Establish a joint working group and special task force composed of multiple national departments, and appoint a national open science coordinator. Let the world understand China' s open science actions, let the public understand national open science plans and funding opportunities, ensure the implementation and coordination of national policies and actions in various institutions, manage the use of open science operating funds, organize monitoring and evaluation of open science development processes, and cultivate and recommend excellent Chinese open science practice cases to the world to achieve Chinese contributions.

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