Analysis of the European Union's Open Science Practice System and Its Implications: Postprint

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Abstract

[目的/意义] Open science constitutes a practical system comprising a series of strategic plans and measures. This study examines the implementation of open science in the European Union to provide actionable references for advancing the open science movement in China.

[方法/过程] Employing web-based research and content analysis methods, this study investigates and analyzes the EU open science practical system from the perspectives of strategic planning and implementation pathways.

[结果/结论] The EU open science practical system embodies a holistic perspective of open science, characterized by high integration and flexibility, and undergoes continuous optimization and improvement. China should elevate open science initiatives to the national level, guided by strategic planning and policies, and ensure the integrity and coordination of its open science practical system through the construction of a unified digital infrastructure, the delivery of open science skills training, the establishment of a next-generation scientometric system, and the creation of collaborative working mechanisms.

Full Text

Analysis and Enlightenment of EU Open Science Practice System

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Abstract

[Purpose/Significance] Open science is a practical system consisting of a series of strategic plans and measures. Investigating the implementation of open

science in the EU provides practical reference for China's open science movement. [**Method/Process**] Through network survey and content analysis, this paper investigates and analyzes the EU open science practice system from strategic planning and implementation paths. [**Result/Conclusion**] The EU open science practice system embodies a holistic view of open science, is highly integrated and flexible, and is constantly optimized and improved. China should elevate open science plans to the national level, guided by strategic planning and policies, build unified digital infrastructure, develop open science skills training, establish a next-generation scientometric system and collaborative working mechanisms to ensure the integrity and coordination of the open science practice system.

Keywords: open science; open access; open research data; next-generation scientometric system; EU

1. Introduction

The advent of the big data era has continuously evolved the logic of scientific research production, with the openness of the scientific domain increasing daily. Scientific research is transitioning from traditional closed models to open models. In recent years, the open science movement has gained increasing attention and become a global consensus. In October 2015, the Organisation for Economic Co-operation and Development (OECD) released *Making Open Science a Reality*, bringing open science into national policy domains [1]. In 2016, the European Commission proposed the vision of "Open Innovation, Open Science, Open to the World" in its report, providing strong support for open science [2]. In December 2017, the OECD World Science Forum and the International Council for Science's World Data System published *Co-ordination and Support of International Research Data Networks*, calling for joint efforts to advance the construction of global data networks to promote open science development [3].

Although open science has not yet formed a unified definition, open access and open data—as important components of open science—are essential contents of national open science strategies and the focus of domestic and international scholars' research. Liu Wenyun et al. investigated open access policies of UK research and education institutions, research funding agencies, and U.S. government departments based on the Registry of Open Access Repository Mandates and Policies (ROARMAP) [6]. S. Haustein et al. studied the citation impact of open access articles using OA DOI to determine the OA status of 67 million articles, confirming the citation advantage of open access [7]. Gu Liping, based on an analysis of current transformations in research models, argued that clarifying stakeholders in research data management, identifying main content of data management, and conducting data sharing policy research are effective approaches to implementing research data management services [8]. Foreign scholars have explored open science from multiple perspectives including tech-

nology and policy. C. Neylon discussed open science development and practice focusing on tools and resources, methodologies, and socio-cultural aspects [9]. G. Juve explored workflows for executing open science using grid, public cloud, or private cloud infrastructures [10]. Currently, domestic research on open science in China remains primarily at the conceptual analysis stage, with Wu Xuechao analyzing the connotation, characteristics, and development models of open science [11], and Chen Xiujuan et al. introducing the meaning of open science, its driving factors, and current advantages and obstacles [12].

Analysis reveals that existing Chinese research primarily explores open science from perspectives of concepts, open access, and open data, which has played an important role in promoting open science development. However, as China's current open science practice system remains imperfect, analysis of foreign open science implementation measures is still needed. The EU has taken a leading position in open science globally, and its practical experience can provide feasible references for China. However, domestic research on EU open science is limited. For instance, Zhang Yu'e et al. introduced EU research data management and open access policies using the EU Research and Innovation Framework Program as an example [13]. Qiu Chunyan analyzed EU scientific data open access progress from four aspects: guidance and practice, institutional support and cooperation, project development, and data repository construction [14]. Shi Zhisong interpreted the *LIBER Open Science Roadmap*, summarizing the transformation of library roles and functions in the open science environment and proposing recommendations for library participation in open science practice [15]. These studies primarily introduce specific aspects of open science or interpret individual European open science projects, without comprehensively analyzing or holistically discussing the entire open science practice system. Building on previous research, this paper uses network survey and content analysis to systematically investigate and analyze the EU open science practice system from strategic planning and implementation paths, aiming to provide reference and enlightenment for China's open science strategy implementation.

2. Open Science Strategic Planning

Strategic planning refers to the overall planning of future goals, guidelines, and tasks. Since the 21st century, the EU has formulated a series of plans for open sharing of research data, scientific research outcomes, educational resources, and software tools, forming a multi-level and diversified strategic framework that lays the foundation for achieving open science goals. Among these, the Horizon 2020 Program and the *LIBER Open Science Roadmap* are important planning guidelines for implementing open science strategies in Europe.

2.1 Horizon 2020 Program

The Horizon 2020 Program officially launched in the UK on January 31, 2014, is the largest research and innovation program jointly participated in by EU member states [16]. To ensure that research outcomes from Horizon 2020 projects

can be promptly discovered, accessed, and reused, the European Commission began fully implementing open research data systems in 2017 to promote EU open science strategy. The open science plan under Horizon 2020 is primarily established through the *Guidelines on FAIR Data Management in Horizon 2020* (FAIR Guidelines) and the *Guidelines on Open Access to Scientific Publications and Research Data in Horizon 2020* (OA Guidelines).

The FAIR Guidelines aim to help Horizon 2020 stakeholders overcome obstacles in the data ecosystem, making research data Findable, Accessible, Interoperable, and Reusable (FAIR principles) to ensure proper data management [17]. The OA Guidelines explain the mandatory open access rules for scientific publications and research data in projects funded or co-funded by Horizon 2020 (see Figure 1 [Figure 1: see original paper]) [18]. The main type of scientific publication is journal articles, while strong encouragement is also given to open access for monographs, books, conference proceedings, grey literature, and other resources. The OA Guidelines identify two primary open access routes: (1) self-archiving/"green" open access, where authors or their representatives deposit published articles or final peer-reviewed manuscripts in online repositories; and (2) open publishing/"gold" open access, where articles are immediately published in open access mode.

The FAIR Guidelines provide standardized guiding principles for research data producers and publishers, maximizing the added value of research data while helping researchers comply with and meet the expectations and requirements of funding agencies. The OA Guidelines emphasize the openness and accessibility of scientific research outcomes and data, providing methods and approaches to guide subsequent data open sharing. As worldwide scientific and technological exchanges and cooperation expand, the FAIR Guidelines and OA Guidelines not only guide open science practice activities in EU member states and organizations but will also extend beyond the EU to profoundly influence open science practice worldwide.

2.2 LIBER Open Science Roadmap

In the open science environment, libraries serve not only as hubs for resources and data but also as builders of open science ecosystems and open service systems [15]. As the main network organization for European research libraries, the Association of European Research Libraries (LIBER) released a specialized strategic plan in July 2018—the *LIBER Open Science Roadmap*—which includes five main components: principles of open science, the entire process of library support for open science, scientific culture transformation, main priorities, and analysis of seven core areas (see Table 1) [19]. The roadmap indicates that libraries play an active role in open science implementation and should participate throughout the entire open science process, including policy planning, service support, resource management, academic publishing, academic evaluation, and outcome reuse. The roadmap also analyzes and introduces opportunities and challenges in seven core areas of open science: academic publishing, FAIR data,

research infrastructure, evaluation and rewards, open science literacy, research integrity, and citizen science, providing action recommendations.

The *LIBER Open Science Roadmap* argues that libraries should become advocates and supporters of open science and expand the impact of relevant actions through partnerships, providing action guidance for European research libraries to implement open science plans. It represents a detailed extension of the "LIBER Development Strategy 2018-2022" in open science deployment.

3. Open Science Implementation Path

Under the guidance of strategic planning, Europe has established the Open Science Policy Platform, implemented the Open Science Cloud plan, launched the FOSTER training project, and undertaken a series of practical measures to support open science strategy. Analysis reveals these measures can be summarized into five aspects.

3.1 Policy Formulation and Implementation

Open science is a gradual process that may encounter a series of problems. Policy formulation and implementation can ensure an orderly and disruptive transition toward full open science, enabling open science goals to be achieved effectively and economically. In February 2013, the EU launched the RECODE project (Policy Recommendations for Open Access to Research Data in Europe), which proposed corresponding policy recommendations for different stakeholders—including research funding agencies, research institutions, publishing institutions, and data managers—based on analysis of opportunities and challenges in open research data processes, establishing an overall policy framework for open access to European research data [20]. The EU also established the Open Science Policy Platform (OSPP) in 2016, an advisory group composed of multiple experts supporting the formulation and implementation of European open science policies. The group's tasks include addressing all aspects of open science, proposing recommendations to the Commission for further policy development and implementation, raising and addressing concerns of the European scientific research community and representative organizations, identifying problems to be solved, and proposing required policy actions to support policy formulation [21].

Both RECODE and OSPP provide guidance and recommendations for open science stakeholders, aiming to coordinate various aspects involved in open science processes, including incentive systems, quality and impact measurement, and information literacy, thereby promoting the formulation and implementation of open science policies at national, funding agency, and research institution levels. For example, in 2016, the EU Ministry of Science and Technology formulated an open access policy for publicly funded research papers, requiring all funded scientific papers to be freely shared starting from 2020. Finland, led by its Ministry of Education and Culture, formulated a national open science policy

framework covering publications, research data, research methods, and tools.

3.2 Infrastructure Construction

Infrastructure construction is crucial for creating an open science ecosystem. To better connect Europe's data infrastructure and ensure data can be used as widely as possible across different disciplines and between public and private sectors, the European Commission proposed the vision of the European Open Science Cloud (EOSC) in its report on the "European Cloud Plan." EOSC will voluntarily unite currently fragmented scientific data infrastructure across different disciplines and member states, providing 1.7 million European researchers and 70 million science and technology professionals with a free, open, and seamless virtual service environment for cross-border and cross-disciplinary research data storage, management, analysis, and reuse, ensuring European scientists fully benefit from data-driven scientific research [22].

The scope of EOSC scientific data sharing is not limited to metadata directly related to research outcomes but also includes associated metadata not directly related. By deploying required supercomputing capabilities, fast connectivity technologies, and high-capacity cloud solutions to European data infrastructure, EOSC creates solutions and technologies applicable to all fields of economy and society, making Europe a global leader in scientific data infrastructure [23]. EOSC provides important infrastructure support for researchers to fully utilize big scientific data, enabling research data sharing and dissemination to transcend geographical, disciplinary, and technological boundaries, and creating a credible open science ecosystem for researchers.

3.3 Open Science Skills Training

3.3.1 FOSTER Training Project FOSTER (Facilitate Open Science Training for European Research) is an EU-funded training project on open access, open data, and open science, aiming to provide a series of support and assistance to different types of stakeholders through various forms including e-learning, blended learning, self-study, face-to-face training, professional training, and workshops [24]. FOSTER has also created an electronic portal platform containing two types of learning resources—learning materials and online courses—open to the world. The core objective of the FOSTER portal is not only to create a platform that can accommodate rich open science materials but also to create an informative and user-friendly platform that respects and meets stakeholders' needs. FOSTER uses taxonomy to systematize training resources in the portal, assigning one or more classification terms to all resources, and employs three access methods—audience-based, knowledge-level-based, and topic-based—to enhance material discoverability and reusability, which is important for helping research users quickly understand various aspects of open science, track and locate knowledge and experts in specific fields.

To promote lasting changes in researcher behavior and make open science the

norm, 11 partners from 6 countries launched the two-year FOSTER Plus project under EU funding [25]. FOSTER Plus specifically emphasizes discipline-specific guidance, enhancing existing materials and co-producing new training content, integrating open science training networks to ensure smooth open science implementation. FOSTER has enhanced European researchers' understanding of open access, open data, and open science requirements, making significant contributions to European Research Area (ERA) participation in open access, compliance with open access policies, and the Horizon 2020 Program.

3.3.2 European Open Science Skills and Qualifications Matrix Europe has undertaken numerous activities in open science skills training. To minimize conflicts and duplication in skills training and bridge gaps at all levels, the European Commission's Working Group on Open Science Skills proposed a European Open Science Skills and Qualifications Matrix in the report *Providing Researchers with the Skills and Competencies They Need to Practice Open Science* (see Figure 2 [Figure 2: see original paper]), recommending that stakeholders strengthen coordination to address fragmentation and duplication in training [26]. Without support from senior leadership, reward systems, incentive mechanisms, and research entities at all levels, the implementation effectiveness of open science skills training will be limited. Therefore, skills training should be coordinated with open science policies and become an important component of them.

The Open Science Skills and Qualifications Matrix integrates career development systems for researchers at all levels, incorporates the FOSTER open science taxonomy into the EOSC taxonomy, and creates an open science competency catalog, distinguishing different learning modes and related certification and recognition mechanisms. This strengthens recognition and rewards for researchers, making open science skills training coordinated, embedded, standardized, scalable, open, adaptable, and mandatory.

3.4 Measurement and Evaluation of Academic Achievements

As open science flourishes, a new research evaluation system should be established to drive scientific research toward greater openness. Traditional evaluation methods that measure researchers' scientific level solely based on journal publications are no longer applicable in the open science environment. The new generation evaluation system should focus more on research quality and its societal impact. The European Commission actively participates in formulating and implementing new open academic measurement standards and encourages researchers to embrace open science as a new research and publication paradigm.

3.4.1 Establishment of Altmetrics Working Group Open science combines new methods and collaborative tools based on research cooperation processes with new ways of disseminating knowledge through online digital technologies. It requires shifting from the standard practice of publishing research

results in scientific journals to sharing all available data and knowledge at the earliest stages of the research process, transforming from "publish as soon as possible" to "share as early as possible." To evaluate existing indicator systems and develop new indicators to promote open science development, the European Commission established a specialized Altmetrics Expert Group in 2016. The group will synthesize problems in current evaluation systems and transform them into recommendations [27]. Since open science has different meanings in different disciplines and national/regional contexts may affect priorities in open research and innovation practices, the expert group will provide different recommendations for specific research fields and propose different requirements for different regions.

To advance next-generation measurement indicators in the open science context, the Altmetrics Expert Group published the report *Next-Generation Metrics and Indicators for Open Science* on March 20, 2017, proposing five important principles for the next-generation indicator system [28]: (1) The open science system should be based on both expert qualitative judgment and quantitative measurement; (2) The development and application of measurement systems should be based on user needs rather than data providers' interests, with transparency and accuracy being crucial; (3) The indicator system should better utilize existing open science indicators; (4) Next-generation indicators should be supported by open, transparent, and linked data infrastructure; (5) Next-generation evaluation standards should focus on the most important and needed metrics rather than the easiest to collect and measure.

Altmetrics emphasizes the importance of using both quantitative and qualitative indicators in research evaluation and the necessity of adjusting evaluation indicators according to specific goals and contexts. Altmetrics has now become a theme on the European open science agenda and will be further developed and implemented with support from the Open Science Policy Platform.

3.4.2 Open Science Career Assessment Matrix To make open science practice mainstream, it must be embedded in the evaluation of researchers at all career stages. The European Commission's Working Group on Open Science Rewards Mechanisms published the report *Evaluation of Research Careers Fully Acknowledging Open Science Practices* in 2017, arguing that evaluation of researchers cannot be reduced to a single number and recommending a multidimensional approach to establish evaluation standards applicable to all sectors, scientific fields, and career stages [29]. To this end, the report proposed the Open Science Career Assessment Matrix (OS-CAM), which provides a comprehensive evaluation of researchers from an open science perspective and has strong feasibility and practicality.

The evaluation indicators include scientific output, research process, service and leadership, research impact, and contributions to teaching (see Table 2), many of which are being incorporated into job descriptions and promotion criteria of research institutions. The matrix elaborates how to recognize and consider re-

searchers' contributions from a broader perspective in the open science context, providing a framework for recruitment and career promotion evaluation methods, funding grant methods, fund allocation models, and incentive measures. Although some evaluation criteria in the OS-CAM matrix can be converted to numbers, weighting can only be part of the process. In any evaluation process, the broad diversity of researchers' experiences and competencies requires further qualitative judgment for sound decision-making.

3.5 Tracking and Monitoring of Open Science Development

To timely track open science development and provide quantitative and qualitative insights for the sustainable development of open science practice, the European Commission's Directorate-General for Research and Innovation commissioned RAND Europe to develop the Open Science Monitor (OSM). OSM aims to provide real-world data and collect the most relevant and timely indicators on open science development in Europe and other global partner countries [30].

OSM monitors the latest progress in open science in real-time from three aspects: open access publications, open research data, and open collaboration, with each aspect including multiple monitoring indicators. Each indicator contains one or several types of data related to that indicator, presented visually through charts and graphs. As a rapidly developing multidimensional phenomenon, OSM improved and updated its monitoring indicators, data sources, and analysis methods in April 2019 to more accurately identify development trends. The study covers almost all disciplines and includes 28 member states (MS) and G8 countries, focusing on analyzing practical factors of different stakeholders. Through OSM, the European Commission can draw conclusions from trends in the quantity and quality of open science and their driving factors, timely adjust strategic planning, and thereby promote continuous optimization of open science.

4. Characteristics of EU Open Science Practice System

4.1 Embodies a Holistic View of Open Science

The holistic view of open science 主张 that open science and its related practices constitute an integrated ecosystem. The European Commission considers open science a source of European competitive advantage, encompassing the entire research lifecycle from conceptualization to reuse, various types of scientific resources from research data to software code, and various stakeholders including researchers, funders, policymakers, citizens, and enterprises [28]. The EU open science practice system includes different components such as open access, open data, open research, and open science tools, involving participation and cooperation from organizations like the European Research Libraries Association, Education and Skills Working Group, European Research Council, and European Commission Open Science Rewards Mechanisms Working Group. It

contains multiple measures and actions in strategic planning, policy formulation and implementation, infrastructure construction, education and training, evaluation system construction, and tracking and monitoring. Different measures and actions are interrelated, and different organizations and stakeholders are interconnected, jointly forming an open science ecosystem.

4.2 Highly Integrated Content

In the EU open science practice system, RECODE and OPSS aim to address and coordinate issues among various open science stakeholders and aspects, EOSC integrates infrastructure in the open science implementation process, FOSTER collects, manages, and presents high-quality training resources, and the Open Science Monitor detects open science implementation progress from multiple aspects. Furthermore, numerous activities exist in open science skills training, with many common and complementary elements in the provided expertise. In the open science environment, researcher performance consists of a complex set of variables, making single evaluation criteria no longer applicable. The EU has achieved high integration of current skills training and evaluation structures through matrix-based approaches. Adjustable learning environments also require multimedia delivery and shared learning resources. FOSTER embeds many video websites (such as YouTube and Vimeo) and video playback plugins into its portal, and resources that cannot be directly downloaded or browsed in the portal, such as blogs and posts, can also be linked from the portal.

4.3 Phased, Iterative, and Flexible Characteristics

The roadmap guides action plan implementation through goal decomposition. The *LIBER Open Science Roadmap* identifies priority actions for library participation in the open science movement. On March 14, 2018, based on the Horizon 2020 Program and extensive stakeholder consultation, the European Commission proposed the *EOSC Implementation Roadmap* [31]. The *EOSC Implementation Roadmap* introduces action steps for EOSC implementation from six aspects: architecture, data, services, access interfaces, rules, and governance, with specific implementation plans and timelines provided for each action guideline. Under the roadmap's guidance, EU open science strategy will be implemented in phases, gradually developing practical measures required for open science, providing consistent access to knowledge services at the European level, specialized open skills training services, and diversified evaluation systems to meet researchers' needs for data sharing, management, and computing.

4.4 Continuously Optimized and Improved System Structure

The EU open science practice system continuously optimizes and improves with the progress of the open movement. Under the Horizon 2020 Program, the ORD Pilot was only implemented in selected specific fields from 2014-2016, but beginning in 2017, ORD Pilot expanded to all fields in the program. With support from the EU Open Science Cloud Program Committee, EOSC access content

will continue to expand, and its functions will become increasingly sophisticated, with user groups extending from initially focusing on the scientific community to the public sector and industry. FOSTER further launched the FOSTER Plus project, specifically emphasizing discipline-specific guidance, enhancing existing materials and co-producing new training content, and integrating open science training networks. The research evaluation system is no longer limited to traditional evaluation indicators but has begun developing next-generation evaluation indicators based on scientific research itself and its societal impact. The Open Science Monitor timely tracks and investigates open science development, providing data support for open science strategic planning and policy adjustment. Through continuous optimization and improvement, the open science practice system maintains sustained vitality, promoting the continuous advancement of EU open science practice.

5. Implications for China

Investigation reveals that Europe's open science practice system is relatively mature and has achieved certain effectiveness. Currently, most countries have adopted, are implementing, or are discussing national-level open access policies for publications and research data; at least two-thirds have national data infrastructure meeting trusted quality standards such as DANS certification, OpenAIRE protocols, and FAIR principles, and have established specialized courses in data processing technology; half are monitoring the development and/or growth of open access publications [32]. In contrast, China's open science remains in the advocacy stage, with activities such as "China Open Access Promotion Week" organized by universities, libraries, and journal publishers. Various infrastructure construction and education training measures are also in their initial stages. To achieve co-construction, sharing, and universal utilization of scientific resources, open science strategy must be elevated to the national level, closely integrated with national policies and regulations, fully utilizing modern information technology to build an open science service system. Based on EU open science cases and measures, China should make breakthroughs and implementations in the following five aspects.

5.1 Guided by Strategic Planning and Policies to Comprehensively Promote Open Science

As a new paradigm of scientific development and a driving force for deepening scientific and technological innovation, open science has attracted increasing attention from international organizations and countries. Europe has currently formed a clear hierarchical open science strategic system from top to bottom, including the "EU Open Science Cloud Plan" at the international level, the *LIBER Open Science Roadmap* at the European library association level, and national-level plans such as Finland's "National Open Science Plan" and France's "Open Science Cloud Plan." Additionally, a multi-level policy system has been formed, with RECODE and OSPP projects helping guide open science policy formula-

tion and implementation. These strategic plans and policies provide guidance for diverse stakeholders including European research funding agencies, research institutions, and libraries to participate in open science practice, forming a solid foundation for comprehensively creating an open science atmosphere and promoting open science development.

Since the 21st century, China has also begun emphasizing open sharing of research data and scientific research outcomes, issuing a series of policies such as the State Council's *Administrative Measures for Scientific Data*, the Chinese Academy of Sciences' *Policy Statement on Open Access to Publications from Publicly Funded Research Projects* and *Administrative Measures for Scientific Data Management and Open Access (Trial)*, and the National Natural Science Foundation of China's *Policy Statement on Open Access to Research Papers from Funded Projects*. However, China has not yet issued policies or plans specifically targeting open science, with open science policies distributed across documents from different government agencies and universities, lacking overall guidance for open science practice. Given the current absence of open science strategic planning and policies in China, the country should follow international trends, draw on advanced experiences from the EU and other countries, and based on national conditions and existing foundations, formulate open science strategies at the national level to guide open science policy formulation and implementation at all levels and across all industries. Furthermore, when formulating strategic plans, different aspects of open science practice should be analyzed and sorted out to establish sound open science plans and guidelines, forming an operable and efficient open science management system. Additionally, dialogue with multi-level stakeholders should be conducted to fully consider the interests and demands of personnel in different industries and institutions, balance various rights and interests, and establish efficient and flexible management mechanisms.

5.2 Utilize Cloud Technology to Coordinate Various Resources and Build Unified Digital Infrastructure

Building unified digital sharing facilities helps break data and information barriers between regions and industries, enhances academic exchange, enables more people to participate in the research process, and forms an open science ecosystem that jointly tackles challenges. Europe will use cloud technology to connect scientific data infrastructure currently scattered across different disciplines and member states, providing European researchers and science and technology professionals with a free, open, and seamless virtual service environment that makes scientific data access easier, more convenient, and effective.

China's existing open science infrastructure mainly includes institutional repositories and research data sharing platforms established by various universities and research institutes. To promote broad access to research outcomes and achieve multi-repository resource sharing, China has begun establishing institutional repository alliances, including the Chinese Academy of Sciences Institutional Repository Grid (CASIRGRID), the China Academic Library and

Information System (CALIS) Institutional Repository Alliance (CHAIR), Taiwan Academic Institutional Repository (TAIR), and Hong Kong Institutional Repository Integration System (HKIR) [33]. However, current domestic digital sharing infrastructure construction lacks overall planning, and a unified open science platform covering all disciplines and categories has not yet been established to enable scientific data sharing among governments, research institutions, and enterprises. In the process of promoting open science, establishing and improving digital infrastructure that ensures resource circulation plays a crucial role in implementing China's innovation-driven development strategy. The 19th Central Politburo's second collective study pointed out the need to accelerate the improvement of digital infrastructure and promote data resource integration and open sharing. EOSC provides a referenceable model for China's open science infrastructure construction. When building unified data infrastructure, China can cooperate with IT service departments and enterprises, fully utilize cloud technology advantages, integrate existing domestic digital infrastructure, build a unified digital resource sharing and exchange system, promote resource interconnectivity, and achieve collaborative management and services of research resources across regions, levels, and disciplines. Simultaneously, it should accelerate the establishment of various standards and norm systems, establish standardized open formats and metadata description formats, develop unified resource identifiers, adopt unified data transmission protocols and scientific measurement standards, and strengthen enforcement through supervision and guidance.

5.3 Strengthen Talent Cultivation and Enhance Open Awareness and Skills

Open science requires skills covering multiple fields from data management to law, including professional technical skills such as data management, data protection, metadata creation, academic exchange, and dissemination. To make open science a reality, researchers need appropriate discipline-related skills training and professional development at all career stages. To achieve this, the European Commission implemented the FOSTER project, providing a series of relevant training programs, practical suggestions, support, and assistance to each type of stakeholder to ensure European researchers have appropriate skills and competencies to practice open science.

Currently, China is in the initial stage of open science development, with its primary task being to raise researchers' awareness of open science practice, enabling them to understand open science policy initiatives, existing institutional and funding agency guidelines, the value of open science practice, and available open science training and development courses. Second, to ensure researchers at all levels can obtain professional development and appropriate skills, multiple forms of online and offline open science training courses should be provided for researchers at different stages. However, training courses alone are insufficient to help researchers conduct open science; they must be supple-

mented with adequate support for open science. Institutions should provide technical infrastructure (high-speed data centers, data warehouses, and virtual platforms), technical tools (software for data creation, storage, and sharing), and support from experts or professionals (data managers, IT technicians, legal experts, discipline-specific data managers, and librarians). In addition to traditional skills enhancement, scientific ethics and research integrity construction, and intellectual property and legal awareness enhancement are also important components of open science skills training. Therefore, funding agencies and research organizations should guide researchers to comply with research rules according to the highest ethical and integrity standards and provide consulting services related to intellectual property.

5.4 Establish a Next-Generation Scientometric System to Reasonably Evaluate Research Performance

With the transformation of academic achievement exchange and publication models, traditional research outcome evaluation systems must also change. One of the biggest obstacles to open science goals lies in the academic research evaluation system. Traditional evaluation indicators such as "impact factor" and "H-index" often fail to identify, evaluate, and reward researchers' efforts in the open science process [34]. Therefore, if researchers adopt new work and publication methods, it will hinder their career development. To effectively measure research performance and reward research teams and individuals who improve work methods, promoting the transition from closed to open science systems, the European Commission established the Altmetrics Working Group and created the "Open Science Career Assessment Matrix." Many countries have also adopted a series of measures, such as the San Francisco Declaration on Research Assessment (DORA) and the Leiden Manifesto signed by multiple countries, and the "Science in Transition" movement initiated by the Netherlands.

In the process of implementing open science strategy, China should also adopt diversified evaluation indicators, formulate comprehensive and systematic evaluation methods, expand the measurement scope of open science research outcomes and research behaviors, and provide more favorable guidance for academic achievement publication and evaluation in the open science environment. Simultaneously, China should actively participate in formulating next-generation scientometric indicator systems globally, strive to enhance the adoption of next-generation scientometric systems, making China not only a participant in open science but also a promoter, demonstrating China's international responsibility and influence.

5.5 Establish Collaborative Working Mechanisms to Ensure System Relevance and Coordination

In the open science practice system, various measures are not isolated but have inherent and close connections. The EU's open science strategic planning guides the open science practice process at the macro level. To meet open science re-

quirements, multiple European organizations have launched various measures and actions in policy formulation and implementation, infrastructure construction, education and training, evaluation system construction, and tracking and monitoring. Policies and measures formulated by various organizations complement each other, jointly promoting Europe's progress toward open science goals.

When implementing open science strategy, China should establish corresponding supporting facilities through collaborative working mechanisms, coordinate various stakeholders' interests, meet the demands of different stakeholders, ensure the open science process while forming a benign open science ecosystem supported by various social organizations and citizens. Additionally, open policies involve intersection and overlap with multiple policies, such as national-level intellectual property protection policies, organizational-level information sharing policies, and resource preservation policies of data storage centers or repositories. Different policies have certain differences, and the compatibility between policies needs to be considered when formulating open science policies to ensure coordination and consistency. Therefore, when formulating open science plans, China should comprehensively consider multiple factors and make efforts in work coordination and policy coordination. More importantly, real-time tracking and monitoring mechanisms should be used to enable the open science ecosystem to develop toward continuous optimization.

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Note: Figure translations are in progress. See original paper for figures.