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Challenges, Opportunities and Future Paths: Environmental Governance of Big Data Initiatives in China

Kai Xu

School of International Law, East China University of Political Science and Law, Shanghai 200042, China; xukai@ecupl.edu.cn

Abstract: Environmental governance is a common task confronting human society in the 21st century. In recent years, China's environmental crisis has been alleviated to some extent by the Chinese government's vigorous regulation. However, as the world factory, China's total greenhouse gas emissions have ranked first in the world for many years, and China still faces a very huge environmental protection pressure. The degree of informationization of China's environmental governance must be improved, with particular emphasis on the collection and use of environmental big data to help transform, upgrade, and improve the efficiency of China's environmental governance. The Chinese government obviously recognizes this and keeps promulgating policy documents related to environmental big data, and there are certain achievements in practice, but it is still in the primary stage of figuring out in general with many imperfections existing. The United States and other countries have more mature experience in the collection and application of environmental big data, which can be an important reference for China. Establishing organizational structures to support the development of environmental big data, striving to form a team of professionals with interdisciplinary knowledge, strengthening relevant legislation for environmental big data, and utilizing international environmental cooperation mechanisms to conduct international cooperation on environmental big data are the areas that China needs to focus on most in the process of improving the collection and use of environmental big data in the future.

Keywords: environmental crisis; environmental governance; big data; pressure on emission reduction; ecological civilization

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1. Introduction

The environmental crisis is a common threat and the many large-scale environmental hazards that occurred in the 20th century have raised people's awareness of the importance of environmental protection. It is almost a consensus that environmental governance is a common task for human society in the 21st century. However, in recent years, the development of environmental governance in the world has been very twisted. In 2017, the U.S. withdrawal from the "Paris Agreement" greatly frustrated and slowed the development of world environmental governance [1]. Although the U.S. has rejoined the "Paris Agreement" since the Biden administration, the indecisiveness of the U.S. has shaken the confidence of many countries around the world on the issue of environmental governance [2]. In 2022, Germany, Austria, the Netherlands, France, and other European countries have cancelled or changed their proposed carbon-neutral targets, which makes a huge impact on the development of environmental governance in the world [3–6].

Against the backdrop of the reality that the world has entered a turbulent period of environmental governance, the Chinese government has nevertheless written the construction of ecological civilization into its Constitution and upgraded environmental governance to one of the country's most important development strategies [7]. In 2020, the leaders of the Chinese government have proposed ambitious dual-carbon goals (carbon peaking and carbon neutrality goals), in which China will increase its independent national contribution,

adopt stronger policies and measures, strive to peak CO_2 emissions by 2030, and achieve carbon neutrality by 2060, which undoubtedly reflects China's great determination to intensify environmental governance [8]. Since China is currently the world's largest emitter of greenhouse gases, it is not easy to achieve the environmental governance goals it has set for itself. This has placed higher demands on China's original environmental governance tools and mechanisms, and advanced information technology is an important grip to help China achieve more effective environmental governance [9]. Information technologies such as big data, cloud computing, and artificial intelligence are developing at a rapid pace, and countries or regions such as the United States and the European Union have already applied these advanced technologies to their own environmental governance and have accumulated a lot of successful experience, so it is extremely important for China to learn from these pioneering countries in environmental protection [10–13].

In fact, although slightly lagging behind some pioneering environmental protection countries, the Chinese government is clearly aware of the value of advanced information technology for environmental governance in China, especially the development and application of big data technology, which will greatly improve the accuracy of environmental governance in China. At the same time, environmental big data is of great significance to China's sustainable development strategy [14–16]. Environmental big data can provide accurate environmental information for China's environmental policy decision makers, helping them better understand environmental problems and formulate effective environmental protection policies. Environmental big data can also achieve real -time monitoring of the environment, helping environmental protection departments to discover environmental problems in time to prevent more environmental damage. Environmental big data can also help China manage and use resources more effectively, and enhance the development of industries related to the environment [17]. For these reasons, big data has been included in China's government work reports for several years since 2014, and in 2018, China's leaders formally proposed China's "National Big Data Strategy". In terms of the combination of big data and environmental governance, China promulgated the "General Plan for the Construction of Ecological and Environmental Big Data" in 2016, proposing to enhance China's environmental governance capacity through ecological big data technology, promote the reform of China's environmental governance system, and provide strong support for the construction of China's ecological civilization [18]. Subsequently, China promulgated the "2018–2020 Ecological Environment Informatization Construction Program" in 2018, providing a more operational landing plan for the introduction of big data technology into China's environmental governance [19]. So far, China has taken substantial steps to improve environmental governance using big data technology and has made certain achievements and accumulated certain lessons in many provinces and regions.

In this context, the purpose of this paper is to examine the development of environmental big data in China, which will not only witness the development of China's environmental protection business but also provide a glimpse into the possibility of achieving China's environmental protection goals and the development direction of China's future environmental protection strategies. It should be noted that there is no official definition of Big Data, and the concept of Big Data used in this paper refers to the information assets of massive volume, high growth rate, and diversity that need new processing models to have stronger decision-making power, insight discovery, and process optimization ability, with four major characteristics: Volume, Velocity, Variety, and Value [20]. Environmental big data can generally be divided into land resource data, ecological environment data, meteorological-climatic data, socio-economic data, disaster monitoring data, etc. Compared with some pioneering environmental protection countries, China's experience in using big data to govern the environment is still relatively limited. Therefore, the comparative research method will be the main research method of this paper. The United States, as the birthplace of environmental big data will be the main target of this paper's comparative study. With the creation of the EPA in 1970, there was an increasing emphasis on collecting and analyzing data related to environmental quality, pollutants, and ecological health. With

the rise of digital technologies and computational capabilities in the late 20th and early 21st centuries, this led to an explosion in the amount and types of environmental data that could be collected and analyzed, giving birth to the concept of environmental "big data". NASA, NOAA and the USGS have also been instrumental in collecting large datasets related to climate, weather, and geological phenomena. Therefore, the United States has world-leading and highly mature experience in environmental governance through the collection and use of environmental big data. While the European Union and other regions will also be explored in this paper in relation to big data environmental governance. The emergence of environmental big data in the European Union has followed a similar trajectory. The European Environment Agency (EEA), established in 1990, has played a key role in collecting and managing environmental data across member states. With the digital revolution, this has grown into big data, with an increased focus on holistic, large-scale analysis of environmental trends. The EU's Copernicus Programme, operational since 2014, is one of the world's leading providers of Earth observation data, contributing to the pool of environmental big data. These experiences can provide extremely valuable references for the use of big data in China. The first part of this paper will systematically sort out the current environmental problems and needs of environmental governance in China, and the second part of this paper will focus on the progress and shortcomings of applying big data to improve environmental governance in China. Finally, this paper will propose recommendations for optimizing the application of big data to improve environmental governance in China.

2. The Current State of Environmental Governance in China and Its Big Data Needs

As we all know, China has made world-renowned achievements in economic development since its reform and opening up, but it has also led to a serious environmental crisis [21]. In the last two to three decades, the Chinese government has invested a great deal of effort in environmental management and achieved notable successes, which have largely curbed the spread of the environmental crisis [22]. But to this day, China is still the world's top emitter of greenhouse gases and still faces the world's greatest environmental pressure in terms of climate change, biodiversity, and soil erosion [23]. Therefore, there is an urgent need to update the technology and institutions of environmental governance in China.

2.1. The Current State of China's Ecological Environment

For a long time, China has been confronted with a serious environmental crisis. Under the huge population pressure, industrial pressure, and market pressure, serious ecological problems such as air pollution, water pollution, waste pollution, soil erosion, and biodiversity reduction have been plaguing China [24]. Upon entering the 21st century, with China's accession to the WTO as an opportunity, the Chinese government began to take a really bold and resolute approach to environmental governance and has made certain achievements so far. According to the "Bulletin on the State of China's Ecological Environment" issued by the Chinese Ministry of Ecological Environment over the past decade, China's pollutant emissions have continued to decline, the quality of the ecological environment has improved significantly, air quality has continued to improve, surface water environmental quality has steadily progressed, and the soil environmental risks have been largely controlled, which indicates that China's natural ecological conditions are generally stable [25].

However, the Chinese government still confronts great challenges in greenhouse gas emission reduction, marine environmental pollution, soil erosion, and rural environmental pollution [26]. For example, China has been the world's largest annual emitter of greenhouse gases since 2006. Between 2005 and 2019, the emissions of greenhouse gases from Beijing, the capital of China, increased by more than 80%. In 2019 alone, China's CO_2 emissions grew by more than 3 percent, and, per capita, China's CO_2 emissions have reached the levels of some high-income countries [27]. Another example is that the marine

environmental pollution problem in China is also extremely serious. On the one hand, in 2020, the area of the South China Sea, the East China Sea, the Yellow Sea, and the Bohai Sea that do not meet the first category of seawater quality standards are 80,080 square kilometers, 48,000 square kilometers, 25,360 square kilometers, and 13,490 square kilometers, respectively; 45,330 square kilometers of sea areas are eutrophic in the summer of 2020, and 9.4% of China's near-shore waters are of inferior category 4 quality. On the other hand, China is one of the main sources of marine plastic pieces. In 2017, Chinese emitters released 1 million tons of plastic waste into the ocean, with notable impacts on fishing and tourism development, and even threatening food security and public health [28]. Another example is that China will still have 2,692,700 square kilometers of soil erosion in 2021, showing that China still has a long way to go to curb soil erosion.

In summary, the current situation of China's ecological environment is that there is a large backlog of historical environmental burdens, and new environmental problems are still being created. In addition, although the Chinese government's environmental governance has achieved some results, the pressure of environmental governance still cannot be underestimated.

2.2. New Features of China's Environmental Governance and Its Big Data Needs

With the rapid increase of China's comprehensive national power, China's environmental governance has been transformed and upgraded from the early days when environmental legislation and administrative management, supervision, and fines were the main modes of governance to an environmental governance system guided by environmental protection strategy, based on environmental legislation and administrative management, and integrated with environmental infrastructure construction, environmental services, and resource recycling [29]. In this realistic context, China's environmental governance presents many new features and urgently needs the support of advanced information technology.

First of all, the automation of environmental protection work is increasing. With the steady development of China's national economy, the scale of cities continues to rise, and the breadth and depth of environmental governance work keep growing, driving the rapid development of the sanitation vehicle and equipment manufacturing industry. At present, various types of sanitation vehicles have been widely used in environmental protection project operations, and the improvement of mechanization has effectively enhanced the quality of service and professionalism. In recent years, the mechanized cleaning rate of urban and rural roads in China has steadily increased. As of the end of 2020, China's urban road sweeping and cleaning area covers 9.756 billion square meters, of which 7.425 billion square meters are swept mechanically, with a mechanized sweeping rate of 76.11% [30]. The increasing level of mechanization in the environmental governance industry will not only improve the quality of operations, but also reduce the labor intensity of sanitation workers, save labor resources, and bring good humanitarian and social benefits [31]. At the same time, the improvement of environmental protection automation can better collect environmental protection data in cities of China, but it also needs more refined governance and a higher degree of information technology for the decision measurement system.

Secondly, the integrated service model of China's environmental governance is becoming increasingly mature. With the continuous promotion of market-oriented reform in the environmental governance industry, integrated and comprehensive operation services have become a significant trend in the development of the industry and are mainly reflected in the following three aspects. Firstly, with the implementation of the rural revitalization strategy, the Chinese government has attached increasing importance to the rural habitat environment, and the coverage of environmental governance activities has expanded from urban areas to the vast number of rural areas for integrated planning and implementation of integrated governance. Secondly, urban environmental governance has developed from basic domestic garbage cleaning to integrated governance covering general solid waste, industrial solid waste, medical waste, sewage, exhaust gas, and other pollutants, which

requires the operator's integrated and comprehensive governance capability to be constantly improved. Thirdly, the operation activities of sanitation projects involve multiple aspects such as sweeping, cleaning and transportation, and comprehensive disposal, which are generally provided by the same operator with a full chain of integrated services, thus clarifying the responsible body and improving management efficiency [32].

In summary, China urgently needs to strengthen the level of information and intelligence of environmental protection, and to improve the ability to collect and analyze environmental big data without delay, especially the integrated application of computer technology, network technology, communication technology, control technology, etc., to improve the operation and management mode of environmental information collection, and to improve the operational efficiency and service level of China's environmental protection system.

3. The Current Situation and Deficiencies of Environmental Big Data Development in China

Nowadays, environmental protection has become a major political issue for the Chinese government, and a major social issue for people's livelihood [33]. Needless to say, China is still facing a serious situation in ecological environmental protection. As the tasks of ecological environment protection in China are expanding, different factors are intersecting with each other, ecological environment problems are becoming more complex, and ecological environment protection and restoration are becoming increasingly difficult. In the era of big data, the protection of the ecological environment will present a new situation.

3.1. The Benefits That Environmental Big Data Can Bring to China's Environmental Protection

China has attached great importance to the status and role of big data in the construction of ecological civilization in recent years and has issued special documents such as the "General Plan for the Construction of Big Data on Ecological Environment", reflecting China's strategic planning for the construction of big data on the environment. Big data for the ecological environment has brought profound impacts and changes to the modernization of China's ecological environment governance system and governance capacity. In general, big data has the following main roles for ecological environmental protection:

First of all, big data technology has played a certain application advantage in ecological environment monitoring and evaluation. It is mainly reflected in the following aspects: for one, it has obviously improved the effectiveness of ecological environment monitoring; for another, it realizes the optimization of data analysis [34].

Secondly, big data technology plays a certain advantageous role in simulating and predicting the ecological environment. On the one hand, it improves the simulation accuracy as well as the prediction efficiency. On the other hand, it realizes the dynamic warning of regional pollution [34].

Thirdly, big data technology is conducive to the modernization of ecological environment governance. First, big data technology can realize the "diversification" of environmental information acquisition. Diversified data sources not only help people to obtain more environmental information, but more importantly, the relevant environmental data can be used for multiple purposes, and combining different environmental data can even generate new environmental science cognition. Second, big data technology can realize the "wisdom" of environmental governance. In the past, environmental information was isolated and segregated according to categories, industries, sectors, and regions, and the correlation and coupling between various types of data and information belonging to the same spatio-temporal object were cut off and forgotten, so environmental governance faced the situation of "information silos" [35]. With the development of big data technology, data dissemination carriers, and big data sharing platform gradually established, environmental big data can more accurately reflect the ecological environment condition, the layout of pollutant emission sources, and the public's ecological environment demands and other information, enabling more accurate prediction of ecological environment quality and its changes, and effective evaluation of environmental pollution governance effects [36].

Fourth, big data has exerted a certain influence on the ecological environment legal system. In the era of big data, China's ecological environment rule of law construction has been further promoted. First, big data is driving the trend of "personalized law," in which legal decisions and rules are optimized to achieve optimal outcomes. Second, the use of big data for ecological environment legislation can transform the traditional legislative model. Big data technology can not only improve people's awareness of the current state of the ecological environment, but also effectively change people's attitudes and thinking about ecological pollution, and urge people to develop a positive environmental awareness [37]. In addition, the use of the big data information platform with structured governance can effectively enhance the sharing of data storage and help people to grasp the corresponding data information query and processing as soon as possible.

To sum up, ecological environment big data construction is an important means for the government to realize accurate ecological management and scientific decision making, an important grasp for enterprises to standardize their sewage treatment behavior and thus realize ecological rule of law, and an important way for the public to actively participate in ecological environment governance and promote the realization of governance diversity.

3.2. The Current Development of Environmental Big Data in China

The study of environmental big data in China started relatively late. From the 1980s to the beginning of the 21st century, with the rapid development of China's information technology and the continuous improvement of information network infrastructure, environmental governance business application systems have formed a certain scale. After the comprehensive construction during the "Eleventh Five-Year Plan" and the transformation and development during the "Twelfth Five-Year Plan", environmental governance entered a new stage of informationization, which laid the data foundation for the application of big data technology on the ground. Since the " Thirteenth Five-Year Plan", with the implementation of the "General Plan for the Construction of the Ecological Environment Big Data", China's ecological environment big data has gradually embarked on the road of rapid development [38] (Tables 1 and 2).

Table 1. Top-level Design Documents Related to Big Data at the National Level in China.

Date of Issuance	Title of the Policy	Contents Related to Big Data
2021	Outline of the Fourteenth Five-Year Plan of the National Economic and Social Development of the People's Republic of China and the Vision 2035	Improve the level of accurate dynamic monitoring and prediction and early warning based on high-frequency big data; strengthen the use of digital technology in responding to public emergencies
2021	The Rule of Law in China Construction Plan (2020–2025)	Building "smart rule of law", using big data regulation, applying big data analysis to provide the basis for legislation
2018	Guiding Opinions on Deepening the Comprehensive Administrative Law Enforcement Reform of Ecological Environmental Protection	Establishing information sharing and big data enforcement and supervision mechanisms, strengthening big data monitoring, relying on big data and other technologies, and using scientific and technological surveillance means
2017	Opinions on Deepening the Reform of Environmental Monitoring and Improving the Quality of Environmental Monitoring Data	Strengthening the application of big data and other technologies to environmental monitoring and quality management
2016	Outline of National Informatization Development Strategy	Improving departmental information sharing mechanisms and establishing a national governance big data center
2016	The 13th Five-Year Plan for Ecological Environmental Protection	Building a big data platform for ecological environment to realize the integration and update of relevant ecological environment data

Table 1. *Cont.*

Date of Issuance	Title of the Policy	Contents Related to Big Data
2016	National Comprehensive Disaster Prevention and Mitigation Plan (2016–2020)	Applying big data and other technologies to disaster response; building a national comprehensive database management system for natural disasters
2015	Outline of Action to Promote the Development of Big Data	Opening up public data in the fields of environment, marine, etc.
2015	Ecological Environment Monitoring Network Construction Program	Promoting the sharing of national ecological environment monitoring data; constructing relevant big data platforms

Table 2. Top-level Design Documents Related to Big Data at the Regional Level in China.

Date of Issuance	Title of the Policy	Contents Related to Big Data
2021	Regulations on the Development of Big Data in Anhui Province	Data resources, big data development and application, big data promotion measures, big data security management, and legal responsibility
2020	Regulations on the Promotion of Big Data Development and Application in Jilin Province	Big data processing, big data development and application, big data promotion measures, data security and protection, and legal responsibility
2020	Regulations on the Promotion of Big Data Development and Application in Shanxi Province	Management and protection of big data development and application and its related activities
2020	Jiangsu Province Ecological Environment Monitoring Regulations	Establishing a data sharing mechanism related to ecological and environmental monitoring, building a province-wide, integrated ecological and environmental monitoring data information platform, docking to the provincial big data center, organizing big data correlation analysis, and sharing related data
2019	Regulations on the Security of Big Data in Guizhou Province	Safety responsibility of big data, big data supervision and management, big data support and protection, legal responsibility, etc.
2019	Jiangxi Province Ecological Civilization Construction Promotion Regulations	Promoting the construction of the province's ecological cloud big data platform, aggregating and fusing the province's data, establishing a basic database, and using big data for analysis, management and application
2019	Regulations on Emergency Protection in Shandong Province	Establishing a database on ecological environment and other topics, promoting the unified collection, sharing, management and application of administrative data at all levels, and providing big data support for emergency protection
2018	Regulations on the Promotion of the Development and Application of Big Data in Tianjin	The government and its relevant departments will promote the opening and sharing of government data, and give priority to promoting the opening of the environment, meteorology and other data in the field of people's livelihood to society
2018	Fujian Province Ecological Civilization Construction Promotion Regulations	Deep integration of the Internet and ecological civilization construction, play the role of big data in the construction of ecological civilization monitoring, protection, services, forecasting, etc.

As can be seen from the above, the current level of ecological environment monitoring in China has been continuously improved, and the monitoring network system in the fields of atmosphere, water and soil has been initially formed, and the monitoring density has

been continuously increased according to the needs of operational management. Up to now, the construction of China's ecological environment big data has achieved its initial results, and big data technology has been applied in the protection of ecological environment, [39] such as the application in data collection, water pollution control, air quality inspection, and environmental protection, etc. [40]. Specifically, the main areas are as follows:

Firstly, the simulation and prediction system of China's ecological environment has been further improved in the context of big data [34]. Big data technology is increasingly used in the current stage of ecological environment simulation and prediction in China. The application of big data technology has played an important role in the current environmental monitoring and early warning and risk assessment of water and atmosphere. For example, the "Green Horizon" platform, jointly developed by the Beijing Municipal Government and IBM with big data technology as the basic premise, enables in-depth analysis of the information data based on the data summary of the emission situation of enterprises in the region, thus achieving highly accurate prediction of air quality in the next 72 h [41].

Secondly, in the context of big data, the government and NGOs have formed a preliminary ecological environment "smart governance" model [42]. In 2016, the Ministry of Environmental Protection (MEP) released the "Overall Plan for the Construction of Big Data for Ecological Environment", which makes "smart" environmental governance an important part of national environmental governance. Encouraged by the central government's policy, governments across China are actively exploring the construction of big data infrastructure for environmental protection [43–46]. In addition to governments at the central and local levels responding to the call to implement environmental management projects with big data, NGOs, especially environmental organizations and private companies, have also developed and put into practice eco-environmental protection plans. With the joint efforts of the government and NGOs, China's ecological protection has achieved good results and formed a model of ecological environment "smart governance".

Thirdly, the pollution management capacity of China's ecological environment has been further enhanced in the context of big data. For example, big data technology plays an important role in the management of water pollution prevention and control [40]. Big data can obtain relevant data through investigation, carry out real-time and effective monitoring of water quality environment in different areas, and quickly transmit the relevant data to the corresponding management departments. Furthermore, big data technology can play an important role in the prevention and control of air pollution. With the continuous promotion of urbanization, the problem of air pollution in cities is becoming more and more serious. The traditional environmental pollution monitoring mode of monitoring and analysis of atmospheric related data is done by meteorological and environmental monitoring departments, and this governance mode has the problem of low efficiency of monitoring and analysis and difficulty of sharing [47]. Big data technology not only improves the efficiency of monitoring and analysis of meteorological data, but also makes the monitoring of data more accurate. In addition, big data technology breaks the barriers of data sharing by establishing a data sharing platform, realizes the unified management of data information from different regions, achieves fast and efficient sharing of environmental data between different departments, and improves the information processing capacity of the data platform.

Fourthly, China's ecological environment rule of law system has achieved initial changes in the context of big data. In the era of big data, the construction of China's ecological environment rule of law system has been further advanced. Firstly, big data is driving the trend of "personalized law," in which legal decisions and rules are optimized to achieve the best results. Secondly, the use of big data for ecological environment legislation has transformed the traditional legislative model. For example, the change of environmental law protection target: from statistical person to specific person; the change of environmental law policy-making model: from causal model to correlation identification; the change of environmental law compliance model: from passive law-abiding person to

active law-abiding person; the change of environmental administrative judicial review: from review expert to review algorithm [42].

3.3. The Deficiencies of China's Environmental Big Data

As mentioned above, China's ecological environment big data technology is developing rapidly and has made remarkable achievements. Although the development of environmental big data technology is effective, it still faces certain difficulties. Specifically, the development of China's ecological environment big data technology is still deficient in the following aspects.

Firstly, the congenital deficiency causes the big data platform of environmental ecological protection is still in the preliminary stage. For one thing, the research on ecological and environmental big data technology in China started in the 1980s, which is a late start, and there is still a gap compared with developed countries, which makes the ecological and environmental monitoring and sensing capability insufficient and restricts the multi-source analysis and application of ecological and environmental big data. In addition, China's environmental data standards are not perfect, which makes it difficult to coordinate and share data between different departments, and it is easy to form data barriers between different departments and between upper and lower levels. Lastly, there is a shortage of complex talents for big data environmental protection, and a professional core team has not been formed [35].

Secondly, the environmental rule of law in the era of big data also faces challenges. To begin with, the collection of environmental big data by both government agencies and NGOs cannot be done without the extensive participation of the public as individuals. Since there are differences in knowledge accumulation, wealth creation and social status among different subjects, it is easy to create a "data divide" [48]. The existence of the "digital divide" will not only bias the samples collected by big environmental data, but also may cause discrimination against low-income groups and create a new round of social injustice. In the second place, the quality of data collection, transportation, use, and analysis may be affected by the defects of the machines and equipment, as well as the uneven ability and quality of the personnel who use them. At last, the process of collecting and using environmental big data may have problems such as violation of privacy protection [49].

Finally, although a preliminary system has been formed, the rule of law of the big data ecological environment is not yet perfect. Although the corresponding legal norms in China have addressed the legislation of big data ecological environment, for example, the Law of the People's Republic of China on Basic Medical Care and Health Promotion and the Law of the People's Republic of China on the Promotion of Small and Medium Enterprises, and the "Rule of Law in China Construction Plan (2020–2025)" issued by the Central Committee of the Communist Party of China (CPC) in January 2021 also proposing to strengthen big data legislation, there are no laws, administrative regulations or departmental regulations specifically for the rule of law of big data ecological environment. At the level of local legislation, local departments have legislated on different types of big data ecological environment for the actual situation in their regions. For example, Shandong, Jiangsu, Fujian and other coastal provinces and some cities have introduced local regulations involving marine ecological and environmental protection. However, these regulations only briefly mention big data in the relevant provisions, and do not apply big data to marine environmental protection in a comprehensive and complete way. Therefore, the rule of law system of big data ecological environment still needs to be further improved [50].

4. Future Development of Environmental Big Data in China

Environmental big data is an important tool to improve China's environmental governance, and can play an important role in improving China's environmental governance system and modernizing its environmental governance capacity. For the future development of China's environmental big data, it is essential to learn from the mature experience of

the United States and other countries and regions, and to make comprehensive optimization on this basis.

4.1. Relevant Experience in the United States and other Countries and Regions

The United States has been the leader of the human information revolution and the birthplace of big data technology, and is currently one of the countries with the most extensive use of big data technology in human society [51]. In terms of ecological environment protection, the U.S. has paid attention to the collection and application of data for a long time. In the 1990s, the U.S. built the Facility Registry System (FRS) to register industrial enterprises, wastewater treatment plants, and civil facilities that have the right to discharge, creating unique identification information for each discharge facility and forming a database for the registration of sewage facilities [52]. The U.S. Environmental Protection Agency (EPA) has also successfully constructed the Environmental Data Registry (EDR), through which comprehensive environmental information and standard information on environmental data (including name, format, source, location, etc.) are provided for government decision-making and public life. In 2012, after the Obama administration issued the "Research and Development Plan for Big Data", the U.S. EPA also paid more attention to the development of environmental big data and its application [53]. From a comprehensive perspective, the U.S. application of big data for environmental protection in environmental governance has the following main aspects worthy of reference for China.

First of all, the U.S. has set up professional environmental big data management institutions to provide a strong guarantee for the collection and analysis of environmental big data. The EPA is the competent authority for environmental big data in the US, and has set up the Office of Environmental Information (OEI) and the position of Chief Information Officer (CIO) to oversee it. The Office of Environmental Information is responsible for the overall management of environmental big data. In addition to the federal EPA, each state environmental protection department in the U.S. has an environmental information office or information specialist, responsible for the collection, upload, maintenance, and release of environmental information. The U.S. practice of setting up a specialized agency for environmental big data has so far resulted in a very mature systematic process of collecting, analyzing, technically processing and releasing environmental big data, ensuring a smooth channel of environmental information from information sources (industrial-type enterprises, environmental protection enterprises, etc.) to society, media and the public [54].

Secondly, the U.S. is vigorously promoting the construction of an environmental data monitoring network. As mentioned above, the Facility Registration System (FRS) is an important grip for the integration of environmental big data in the U.S., and is centrally managed and maintained by the U.S. EPA's Office of Environmental Information Technology [55]. At the same time, the U.S. EPA has constructed the Environmental Facts Database (Envirofacts), an environmental data query system that provides the public with access to environmental information including air, water, waste, toxics, radiation, soil, maps, and the like [56,57]. The EPA's transmission and sharing of environmental data is enabled by the Central Data Exchange (CDX), a fast and accurate network for exchanging real-time environmental data, which is built with the latest and secure information technology to connect the federal government, local governments, businesses, and EPA's subdivisions [58].

Further, the United States has introduced a strict environmental protection system to ensure that businesses provide accurate data. The EPA obtains data and information primarily through a strict corporate reporting system for pollutants, rather than through regular or irregular pollution censuses or surveys. Where hazardous substances are regulated, the emitters are obligated to report. Underreporting, omission or inaccurate reporting may lead to serious fines. Because of the strict penalty system, it is a very risky practice for companies to dishonestly report their pollutants or hazardous substances. Once discovered by environmental authorities, or by the public, in addition to paying fines, their business reputation will be seriously damaged [59].

After more than thirty years of construction, the U.S. collection and application of environmental big data has greatly improved the efficiency of U.S. environmental governance and played an irreplaceable role in the improvement of the U.S. ecological environment. In addition to the United States, there are many other countries that attach importance to environmental protection and have accumulated valuable experience in environmental big data. For example, Germany started soil condition testing in 1986. At present, Germany has established about 800 monitoring sites in 16 federal states to regularly sample soil and monitor its physical, chemical and biological properties to understand changes and trends in soil. In addition, Germany has established a comprehensive database system for soil information, which includes geological data, soil trends and contaminant data. This database system collects and analyzes information on soil function, quality, and contamination to upport federal and state measures for soil pollution prevention and control [60]. In 2009, for example, the European Environment Agency (EEA) released its groundbreaking application Eye On Earth, which allows users to view the water and air quality of the EEA's 32 member states through high-definition Bing maps [61,62]. The EU Council adopted the Data Governance Act in May 2022 to build a new data sharing and analysis model for environmental information, intelligent transportation, industrial information, and public health and medical information. In a word, environmental big data will play an increasingly important role in human environmental governance, and China, as the world's largest country in terms of pressure to reduce emissions, must make good use of environmental big data.

4.2. The Path to Improve Environmental Big Data in China

The first is to establish an organizational structure to support the development of environmental big data and implement integrated environmental data management. China must build a specialized environmental big data management institution in order to strengthen ecological environment monitoring and sensing capabilities, develop unified environmental data measurement standards, break down data barriers, and strengthen data coordination and sharing among various departments [63]. At the same time, China should strengthen the construction of remote sensing capacity for ecological environment monitoring, establish a multi-level linked database at national, provincial, municipal and county levels, enhance data sharing, and lay a solid foundation for the construction of ecological environment big data. It should also improve the level of simulation and analysis of ecological environment big data, open up the relationship between ecological environment elements, and enhance the accuracy and timeliness of big data prediction [64]. When China uses big data technology to collect ecological environment information, it needs to develop a unified environmental data standard first, so that different subjects can collect relevant information more efficiently and realize the sharing of resources to avoid duplication of efforts.

The second is to strengthen the exchange and communication of talents between different disciplines and strive to form a professional reserve force with cross-disciplinary knowledge. The cultivation and construction of a big data ecological environmental protection team requires the joint communication and cooperation of diverse talents. In the process of building the talent team, it is possible to widely absorb highly skilled talents from various fields such as law, electronic information, geographic information, and applied mathematics, and conduct regular training to learn and borrow advanced experience and knowledge from different disciplines and developed countries to form a "composite" talent team of "environmental protection + big data" [65].

The third is to strengthen the legislation related to ecological and environmental big data, improve the quality of legislation, and establish a special environmental and ecological big data management agency. At the time of rapid development of big data technology, it is necessary to set up a special administrative law for the safety and use of big data. The construction of ecological environment big data legal norms should be combined with the current situation of domestic ecological environment protection of big data, learn from foreign advanced legislative experience, and develop legal norms that

meet the national conditions and have international vision, including but not limited to: ecological environment big data monitoring and early warning system, ecological environment big data security management system, ecological environment big data pollution management system, ecological environment big data information sharing system and ecological environment big data personal privacy protection system, etc. [66]. After the establishment of the overall ecological environment big data protection system at the central level, the local departments at all levels can refine the relevant legal norms according to the actual situation and local features of the region to form a relatively complete ecological environment big data legal system from the central to the local level [67].

In addition to the above three aspects, China should also pay attention to the cooperation on environmental big data with the help of international environmental cooperation platforms. It is recommended to use the existing environmental cooperation mechanisms between China, the United States and China-EU to carry out exchange activities on environmental big data and provide conditions for training technical and management talents in environmental informatization [68]. It is important to learn the experience of environmental information disclosure policies from developed countries such as the United States and introduce advanced technologies, such as environmental data analysis models and information disclosure platforms, to provide technical support for the construction of big environmental data in China.

5. Conclusions

Following the rapid development of information technology, data is becoming more and more valuable to human society. As an important information carrier, data records various activities of individuals, enterprises and governments. Big data technology is to summarize the experience and strategies that are beneficial to the development of human society from the huge amount of data, and when this technology is applied to environmental governance, it can greatly improve the efficiency and governance level. For a long time, China's statistics and environmental protection departments have collected considerable data in environmental governance, but these valuable data have not been fully utilized, and there is still a large lack of environmental crises early warning, environmental disaster control, and accurate grasp of regional environmental problems. In the era of booming big data technology, China's environmental protection departments can collect environmental big data and then combine it with information from various environmental indicators for effective analysis. With big data technology, China's environmental protection departments can reasonably and objectively predict the scope of pollution sources, the distribution of pollution sources, major pollution sources, and the various impacts that pollution sources can have on the surrounding environment, thereby reducing the cost of environmental management and improving the efficiency and effectiveness of environmental management. The decision makers of China's environmental protection policy and China's environmental protection departments must conscientiously refer to the mature experience in environmental big data in the United States, the European Union, Germany and other countries, enhance the awareness of environmental protection decision -making, and continuously stimulate the environmental big data related scientific research and technological innovation, leading China's future environmental protection to truly rely on scientific and technological power, rather than relying on China's administrative forces. Only by doing so will China be able to achieve the dual-carbon goals (carbon peaking and carbon neutrality goals) it has set for itself and make more contributions to the world's environmental protection cause.

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