GREEN DEVELOPMENT RESEARCH IN CHINA: A BIBLIOMETRIC ANALYSIS AND SYSTEMATIC REVIEW

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Abstract. China has systematically incorporated the principle of green development into all dimensions of its economic and social progress, thereby forging a unique pathway that effectively harmonizes ecological preservation with the enhancement of public welfare while contributing a meaningful Chinese approach to global sustainable development. This study provides a systematic review of academic papers and grey literature on the topic since 1999 by descriptive and bibliometric analyses. The results indicate that green development research comprises of initial germination phase, exploratory rising phase, and vigorous developmental phase. The research focuses on six green development-related aspects: connotation, measurement level, influencing factors, institutional innovation, transformation, and agriculture. The research frontiers include green finance, and green technological innovation. Furthermore, diversified practices of China's green development are listed by supplementing grey documents and practices. Based on the literature and ongoing practices, we explain China's green development model and conclude four major challenges: significant pressure for the transformation of the energy structure, bottleneck in green technological innovation, imbalance in green development among regions, insufficient promotion of green lifestyles. This review will provide a systematic reference for scientific communities, policymakers, and practitioners in China and in developing countries, facilitating further exploration of theoretical and practical innovations of green development.
Keywords: *temporal distribution, journal distribution, research hotspots, research frontiers, mapping knowledge domains*

Introduction

As the global population continuously grows and urbanization accelerates, resource consumption and environmental losses due to global economic and social development are increasing (Liu and Chang, 2016), crucially threatening the sustainable development of mankind. Green development is an intrinsic requirement for effectively responding to the severe resource and environmental scenario, and for proactively adapting to the transformation of social contradictions, and achieving the "double carbon" goal on schedule (Fang, 2022). Green development refers to a new model of achieving sustainable economic, social, demographic, resource and environmental development under the limitations of resource availability and environmental carrying capacity (Shao et al., 2021). Following the initiation of the Global Green New Deal by the United Nations Environment Programme (UNEP) in 2008, green development has become the consensus among a growing number of nations and regions worldwide, evolving into a crucial method for achieving global sustainable development (Ren and Ma, 2020). During the United Nations Conference on Sustainable Development, held in Rio de Janeiro, Brazil, in 2012, green development was officially recognized as a key approach to achieving sustainable development. In 2015, the United Nations Sustainable Development Summit

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endorsed the 2030 Agenda for Sustainable Development, which emphasized the importance of global environmental protection in tandem with economic development (Scharlemann et al., 2022; Warchold et al., 2021). China has always attached great importance to green development, which is an economic development model that can both enhance public welfare while protect the environment (Lyu et al., 2022; Huang and Ye, 2021). The green development concept has gradually become a key guiding principle in China, driven by economic development and societal progress. The Fifth Plenary Session of the 18th Central Committee of the Communist Party of China proposed that China should adhere to green development and advance the development of ecological civilization. In 2024, China's Government Work Report highlighted the necessity of advancing the coordinated progress of carbon reduction, pollution control, green development, and economic growth, while accelerating the comprehensive green transformation of economic and social development. China has made remarkable progress in green development and made substantial contributions to global sustainability efforts. As a developing country, China's green development merits worldwide attention.

China acts as an active participant, a major contributor, and a leading force in the theory and practice of green development (Shang et al., 2020). China's green development policies have been consistently implemented, and its achievements have continuously benefited individuals' livelihoods, and a systematic and comprehensive green development system is being established at an accelerated pace. By incorporating the ecological principles of socialism with Chinese characteristics into its development strategies, China has provided innovative solutions to promoting global sustainable development (Lin et al., 2019; He et al., 2017). Owing to China's rapid economic growth and rising global influence, its practical experiences and theoretical advancements in green development have increasingly attracted scholarly attention worldwide. Furthermore, the theories, analytical tools, methodologies, and technologies applied in green development research are constantly advancing. China's green development endeavors have achieved remarkable outcomes across multiple domains. Currently, there is a pressing need to further extend the research on the current situation, hotspots, frontiers, diversified practices, and challenges in this field.

Therefore, it is necessary to conduct a systematic review of China's green development. This review can effectively highlight the research progress, explore the intrinsic connections and development patterns of the research topic, and hold crucial theoretical and practical significance for further advancing research and practices. Theoretical significance: (1) Enrich the global sustainable development theoretical framework; (2) Make valuable contributions to green development research, helping to further refining and strengthening the scientific foundations of green development theory; (3) Construct a comprehensive and systematic theoretical basis for advancing green development research. Practical significance: (1) Provide replicable and scalable transformation experiences for global adoption; (2) Serve as a valuable reference for government departments in formulating evidence-based guiding strategies; (3) Enhance public awareness of green development concepts in production and consumption, thereby fostering broader societal support for green development initiatives.

This research aims to offer a comprehensive perspective on promoting green development by systematically reviewing 1613 journal articles and 48 grey documents, along with pragmatic cases of green development in China. Firstly, a quantitative analysis is conducted to investigate the characteristics of green development research. Secondly, research hotspots are identified and subjected to manifest content analysis. Subsequently,

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the practices of green development in China are systematically summarized, and the green development model is elaborated. Lastly, the major challenges and prospects of green development are thoroughly discussed. Ultimately, this study seeks to provide valuable insights and references for China and other developing countries in further promoting green development.

Materials and methods

Research scope

Journal literature and grey documents related to green development were selected as the research scope. Specifically, journal articles indexed in the Chinese Social Sciences Citation Index (CSSCI) database were retrieved. As a core journal evaluation system with significant influence, the CSSCI database indexes the most advanced and comprehensive research findings within specific disciplines, thereby ensuring the comprehensiveness and authority of the collected data (Li et al., 2018; Zhu et al., 2019). Using "Title = Green Development" as the search term, the earliest literature was traced back to 1999. Consequently, this study defined the timespan for the literature search as 1999-2024. After excluding invalid data, including records with low relevance to the topic, conference announcements, prefaces, individual scholarly presentations, book reviews, entries without authors, and duplicates, a total of 1613 bibliographic records were retained. The relevant literature records were subsequently exported and saved in RefWorks format (Wang et al., 2020a). To meet the data format requirements for mapping knowledge domains, the exported data were processed using CiteSpace's data conversion function to prepare for subsequent analysis. The 1613 literature entries constituted the total sample pool, which played dual roles in the research: supporting bibliometric analysis and underpinning the scientific review. All 1613 literatures were included in the analysis, and only bibliographic information was extracted for quantitative characteristic analysis aiming to ensure the representativeness of the bibliometric results. Meanwhile, core literatures were screened based on innovation and representativeness for in-depth analysis, with their contributions to theoretical frameworks, empirical findings, and methodological applications serving as the content foundation for the review section (*Fig. 1*). Furthermore, 48 grey documents related to the research topic were collected in recent years, including 33 official documents and notifications from the Chinese government and 15 reports from non-governmental organizations.

Research methods

The methods employed in this review comprise quantitative analysis and manifest content analysis (*Fig. 2*). Bibliometric analysis enables the quantitative analysis of the characteristics of a large body of literature, thereby identifying the research status, development trends, and academic frontiers of a field while addressing the limitations of subjectivity and arbitrariness inherent in qualitative research (Wang, 2023). Mapping knowledge domains refers to visualizing the knowledge of a field through a series of processes, including data mining, information analysis, scientometrics, and graphical mapping with knowledge navigation functions, and is a subfield of bibliometrics (Zhang et al., 2018). CiteSpace demonstrates obvious advantages in sorting out relevant research topics, evolutionary processes (Bengtsson, 2016). Manifest content analysis, as a pivotal method in qualitative content analysis, closely engages with the text to directly extract

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and present the ideas conveyed by authors (Tan et al., 2017). We conduct a manifest content analysis of research hotspots and frontiers for green development based on keyword co-occurrence and strongest citation bursts. Since quantitative analysis and manifest content analysis, we put forward challenges and prospects by integrating insights from journal literature, grey documents, and green development practices.

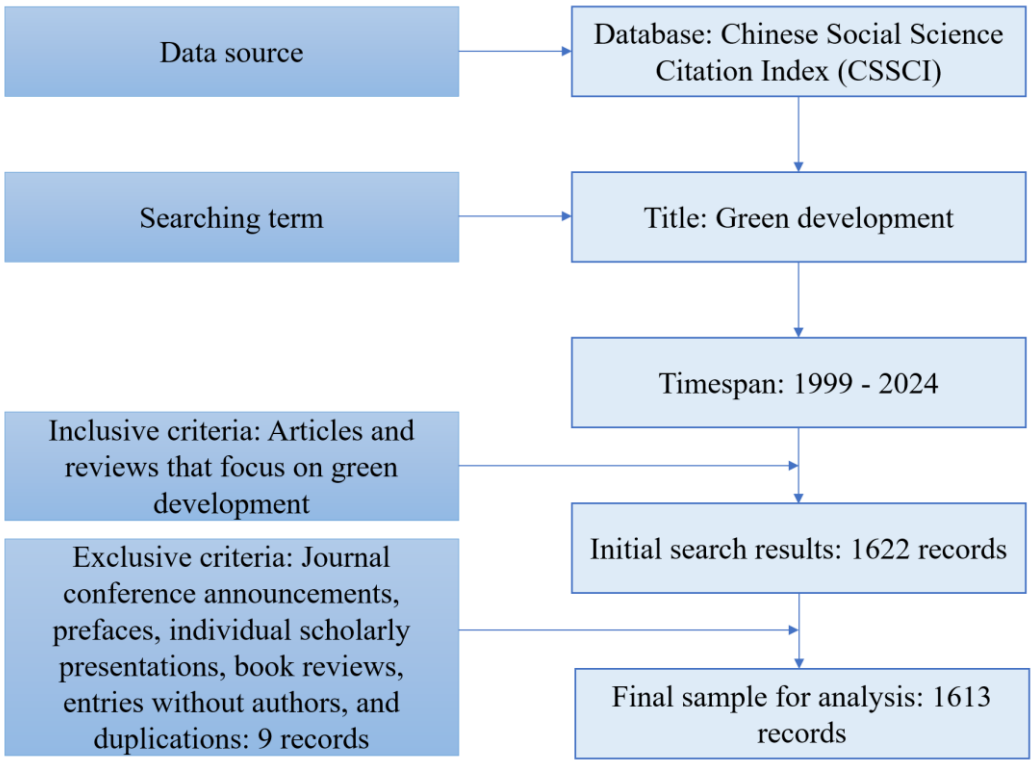

Figure 1. *Flow chart of sample selection process and criteria*

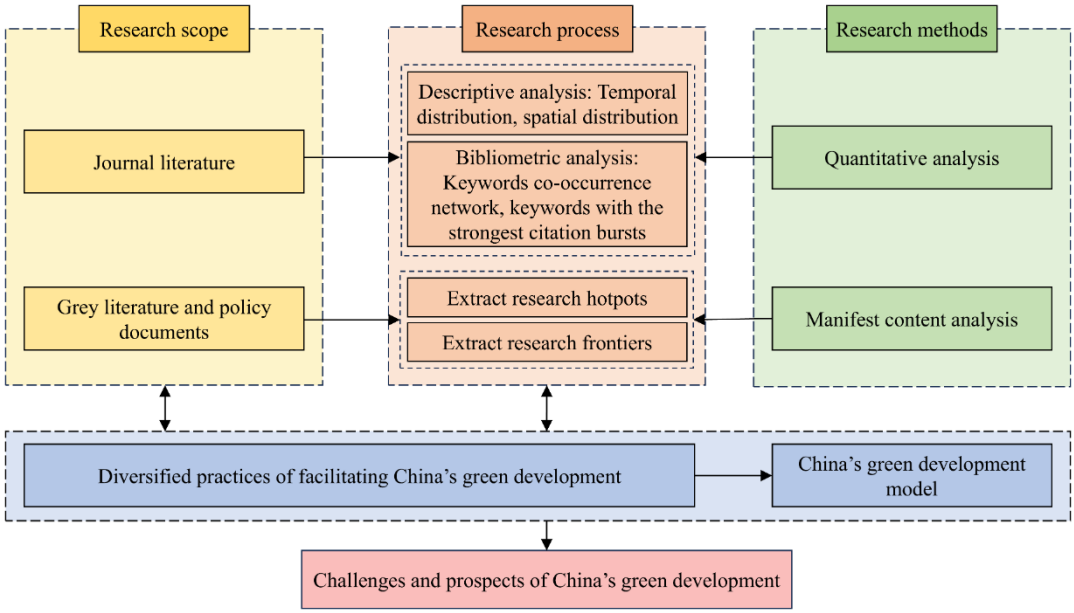

Figure 2. *Schematic diagram of the review*

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Analysis of temporal distribution

The quantity of publications is a crucial metric for evaluating the status and development direction of a field's research, which helps visualize the changes in research intensity within a specific period, and is important for assessing the dynamics of the field and forecasting future trends (Chen et al., 2015). By analyzing the research outputs on green development, a statistical chart illustrating temporal distribution can be obtained (*Fig. 3*).

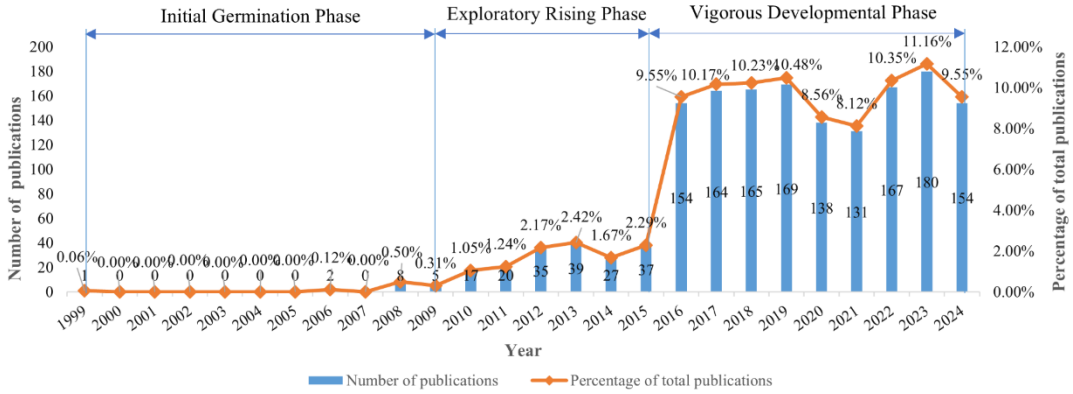

Figure 3. *Temporal distribution of green development publications in China, 1999-2024*

As illustrated in *Figure 3*, China's green development-related publications exhibit an obvious overall upward trend from 1999 to 2024, with distinct phase-specific characteristics, which indicates that research on green development has been progressively gaining more attention. Based on the temporal distribution characteristics, it is evident that green development research in China has roughly undergone three phases: (1) the initial germination phase from 1999 to 2009, during which the number of publications shows a gradual upward trend; (2) the exploratory rising phase from 2010 to 2015, during which the number of publications displays a fluctuating growth; and (3) the vigorous developmental phase from 2016 to 2024, during which the number of publications exhibits a rapid growth.

A. Initial germination phase (1999-2009)

During the initial germination phase, there is a scarcity of literature related to green development. Only 16 articles were published over an 11-year period, accounting for 0.99% of the total, with an average of approximately one article per year. In the early stage of a field research, there are relatively few publications due to the lack of sufficient relevant theories and foundational knowledge. However, with the advancement of practice and the promotion of relevant policies, an increasing number of researchers and research institutions have entered the field, leading to more in-depth studies. Consequently, the number of publications has increased and gradually stabilized (Chen et al., 2015). The research at this stage primarily centered on the theoretical analysis of the concept of green development, as well as on exploring the importance and feasibility of adopting green development. The articles were predominantly grounded in content analysis and theoretical exploration. Chinese academics emphasized that green development can enhance China's international position during this period. Furthermore, they proposed that China should pursue green development by embedding the concept

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into policy formulation, industrial upgrading, and economic adjustment. However, at this stage, Chinese scholars have predominantly focused on macro-level analyses, failing to delve into the possible role and influence of the green development at the micro-level.

During this phase, China initially established a policy framework for green development, transitioning from end-of-pipe pollution control to source-based pollution control. Policies and practices focused on the preliminary coordination between economic development and environmental protection. In 2000, the National Outline for Ecological and Environmental Protection was promulgated, which for the first time explicitly set the overarching goal of "maintaining ecological balance and improving the ecological environment," and proposed a strategy of "classified guidance and region-specific advancement" for ecological conservation. The 11th Five-Year Plan (2006-2010) incorporated "lowering energy consumption per unit of GDP" as a binding indicator for the first time, marking a milestone that moved green development from conceptual advocacy to the stage of quantitative regulation. In 2007, the 17th National Congress of the Communist Party of China officially put forward the concept of "promoting ecological civilization," elevating ecological conservation to "a crucial dimension of human civilization development." It also set the target of "basically forming an industrial structure, growth model, and consumption pattern that are energy-efficient, resource-conserving, and environmentally friendly," thereby laying a solid conceptual foundation for green development to progress from "germination" to "exploration" after 2009.

B. Exploratory rising phase (2010-2015)

The number of publications increased significantly compared to the previous period. A total of 175 articles were published over the 6-year period, accounting for 10.85% of the total, with an average of approximately 29 articles per year. Notably, the number of publications shows some volatility, as the relevant research is still in its exploratory stage. The year 2010 marked the conclusion of China's Eleventh Five-Year Plan (2006-2010) and simultaneously served as the year for formulating the Twelfth Five-Year Plan (2011-2015). The Twelfth Five-Year Plan positioned green development as a critical proposition, emphasizing its role as a fundamental requirement under the guidance of the scientific development concept. In 2015, the Paris Agreement, a global accord on emissions reduction involving nearly 200 countries and regions, was reached. This agreement represented a historic and significant milestone in the global efforts to address climate change. In response, China actively aligned with these requirements by proposing a green development strategy. With the deepening of national policies and the implementation of the green development strategy, more scholars began to focus on theoretical exploration in this field. The distinctive feature of this stage is the rapid expansion of the research scope, which transitioned from macro-theoretical discussions to applications in key areas such as China's urban development, economic growth, ecological civilization construction during this exploratory rising phase. Regarding research methodology, compared with the previous stage, the use of empirical research methods became significantly more frequent. Scholars are more inclined to use rigorous mathematical logic, scientific modelling methods, and intuitive data measurement results to investigate green development in China. China's practical and academic communities are increasingly engaging in the exploration of green development. However, the promotion of green development encounters numerous challenges and constraints, primarily due to the lack of institutional systems compatible with green development and insufficient clarity in development path selection.

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During this phase, China's top-level design for green development became more systematic, with diversified governance tools. Policies and practices focused on the synergistic advancement of economic transformation and ecological conservation. In 2010, multiple central ministries jointly issued the *Guiding Opinions on Promoting Joint Prevention and Control of Air Pollution to Improve Regional Air Quality*, establishing a regional joint prevention and control mechanism that transcended traditional administrative boundaries. The 12th Five-Year Plan (2011–2015) included green development as a standalone chapter for the first time. It introduced the binding indicators such as arable land retention, forest growth, the proportion of non-fossil fuels in primary energy consumption, and integrated resource and environmental indicators into the performance appraisal systems of local governments. In 2012, the 18th National Congress of the Communist Party of China established "Building a Beautiful China" as the overarching goal for ecological civilization construction. It emphasized adhering to the basic national policy of resource conservation and environmental protection, prioritizing conservation, environmental protection, and natural restoration, and striving to promote green, circular, and low-carbon development. In 2015, the Fifth Plenary Session of the 18th Central Committee of the Communist Party of China innovatively proposed the Five Major Development Concepts: innovation, coordination, green development, openness, and sharing. This elevated green development to be one of the key concepts for economic and social development, moving from quantitative regulation to comprehensive implementation of green development. These efforts laid a solid foundation for the subsequent formulation of the "dual carbon" goals (carbon peak and carbon neutrality) and the advancement of ecological civilization construction.

C. Vigorous developmental phase (2016-2024)

The number of publications increased sharply, reaching 1422 over the 9-year period, accounting for 88.16% of the total, with an average of approximately 158 articles per year. In 2024, the Third Plenary Session of the 20th Central Committee of the Communist Party of China highlighted the deepening of the ecological civilization system reform as a pivotal element of comprehensive reform. It systematically delineated measures to refine and enforce the institutional mechanisms that underpin the principle that "lucid waters and lush mountains are invaluable assets," thereby mapping out a clear direction for China's green development. Green development has grown in significance and is progressively gaining international recognition. In China, it has also entered a new phase, drawing increasing attention from scholars and prompting extensive interdisciplinary research. In terms of research domains, green development has further expanded into finance, rural revitalization, the Belt and Road Initiative, and targeted poverty alleviation. Regarding its theoretical connotation, green development has gradually evolved into a comprehensive development concept that integrates economic, social, and environmental dimensions in a coordinated manner. This stage is notably characterized by a significant expansion of the research scope and its closer integration with the national strategies. The concept of "green development" has become much more comprehensive and in-depth at this stage compared to the previous one. It now plays a crucial role in national strategy, human development, and societal progress, thus extending beyond its earlier focus on ecological civilization construction and environmental governance.

During this phase, China's green development policies were deepened, and practical initiatives were comprehensively rolled out. Both the policies and practices focused on the in-depth integration of high-quality economic development and high-standard

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ecological conservation. In 2016, the Ministry of Environmental Protection (MEP) announced the Environment Day theme as "Improve Environmental Quality and Promote Green Development," with the aim of mobilizing and guiding all sectors of society to embrace the concept of harmonious coexistence between humans and nature. In 2017, the 19th National Congress of the Communist Party of China emphasized the significance of establishing an economic system centered on green, low-carbon, and circular development. It also highlighted the necessity of accelerating the development of legal frameworks and policy guidelines that encourage green production and consumption. In 2020, President Xi Jinping put forward the "dual-carbon" goals (carbon peaking and carbon neutrality) in his speech at the General Debate of the 75th Session of the United Nations General Assembly. Centered on these goals, China has adopted a series of proactive and effective green development policies and actions, which have yielded remarkable results. In 2022, the 20th National Congress of the Communist Party of China elevated the initiative of "promoting green development and fostering harmony between humanity and nature" to an entirely new strategic height, and proposed the strategy of "pursuing the synergies of carbon reduction, pollution mitigation, green areas expansion, and economic growth". This has provided a fundamental guideline and action framework for China's green development. China's green development has entered a new developmental phase characterized by systematic advancement and enhanced synergy in efficiency.

Analysis of journal distribution

The journal distribution of literature can be described by Bradford's Law (Qiu et al., 2019). The degree of professional relevance of the source journals has a positive correlation with their frequency of appearance; thus, based on the change in the number of publications carried by the journals, the journals can be classified into the core, related, and marginal areas (Li et al., 2014). Green development research literature is non-uniformly distributed in relevant journals. According to Bradford's law of literature distribution (Wei et al., 2023; Wang et al., 2020b), the number of core areas is calculated as *Equation 1*.

$$r_0 = 2\ln(e^E \times Y) \quad \text{(Eq.1)}$$

where: r_0 = number of core journals, E = Euler's constant = 0.5772, Y = maximum number of publications in a single journal.

In this study, Y is 172, so there are 11 journals distributed in the core area: Environmental Protection (Environ. Prot.), China Population Resource and Environment (Chin. Pop. Resour. & Environ.), Statistics & Decision (Stat. & Decis.), Journal of China Agricultural Resources and Regional Planning (Chin. J. Agric. Resour. & Reg. Plan.), Science and Technology Management Research (Sci. & Tech. Mgt. Res.), People's Tribune (People's Trib.), Economic Geography (Econ. Geogr.), Resources and Environment in the Yangtze Basin (Resour. & Eviron. Yangtze Basin), Soft Science (Soft Sci.), Ecological Economy (Ecol. Econ.), and Macroeconomic Management (Macroecon. Mgt.). A total of 484 articles, accounting for 30.01% of the total sample were published in these 11 journals (*Fig. 4*).

The distribution of journals in the core area shows that research on China's green development is characterized by a coexistence of concentration and dispersion. The majority of research outputs are concentrated in disciplines including agricultural

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resource science, geographical science, and economics. Nevertheless, apart from these 11 journals, many other journals also publish research on this topic. Although the number of articles published in any single journal is limited, this reflects a significant characteristic of interdisciplinary integration. Green development research has extended into multiple disciplinary domains, ranging from quantitative statistical analysis to philosophical-level theoretical exploration. Notably, this interdisciplinary research not only highlights the substantial attention paid by the academic community to green development but also provides multidimensional theoretical support and decision-making references for the green development strategy including policy formulation and implementation pathway optimization.

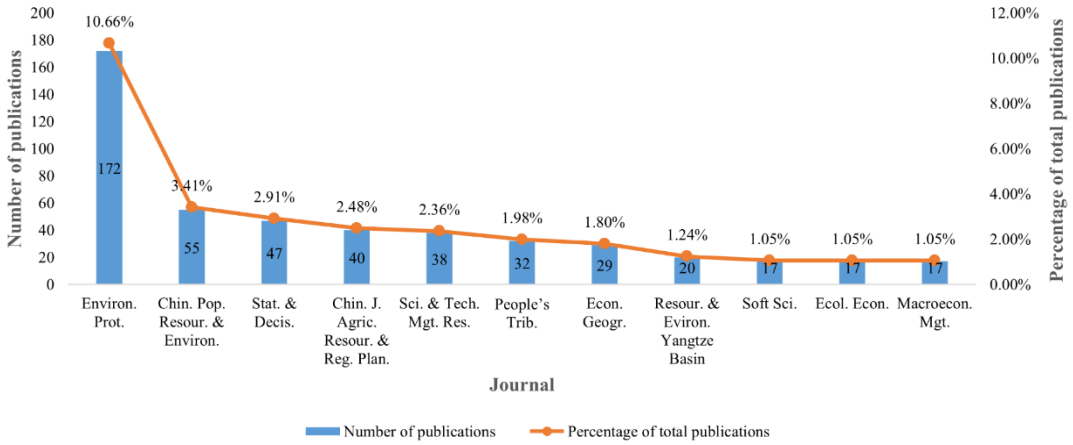

Figure 4. *Journal distribution of green development publications in the core area of CSSCI source journals, 1999-2024*

Analysis of research hotspots and research frontiers

Analysis of research hotspots

China's unique development context offers valuable empirical data for green development research. Although research in this area started relatively late, it has yielded increasingly significant findings. Keywords play a crucial role in conveying the most essential and central information, providing a highly concise summary of theses' main ideas (Luan and Jiang, 2008) and representing a concentrated manifestation of research themes. The frequency of keywords has a positive correlation with research hotspots (Luo and Yu, 2017). Analysis of high-frequency keywords enables the identification of research hotspots in a specific field. Therefore, a keyword co-occurrence network analysis is conducted on 1613 publications using CiteSpace. The Node Type is set as Keyword, the threshold is set to T30, and the remaining parameters are left as default. This process has generated the keyword co-occurrence network mapping (*Fig. 5*).

As shown in *Figure 5*, the keywords "green development", "green development concept", "green development performance", "green development efficiency", "influencing factors", "environmental regulation", "green transformation", and "green growth" are found to frequently co-occur. By conducting the statistical analysis and systematic review of the literature associated with key nodes in the keyword co-occurrence network mapping, the following research hotspots have been identified and summarized according to the high-frequency keywords and their correlation degrees.

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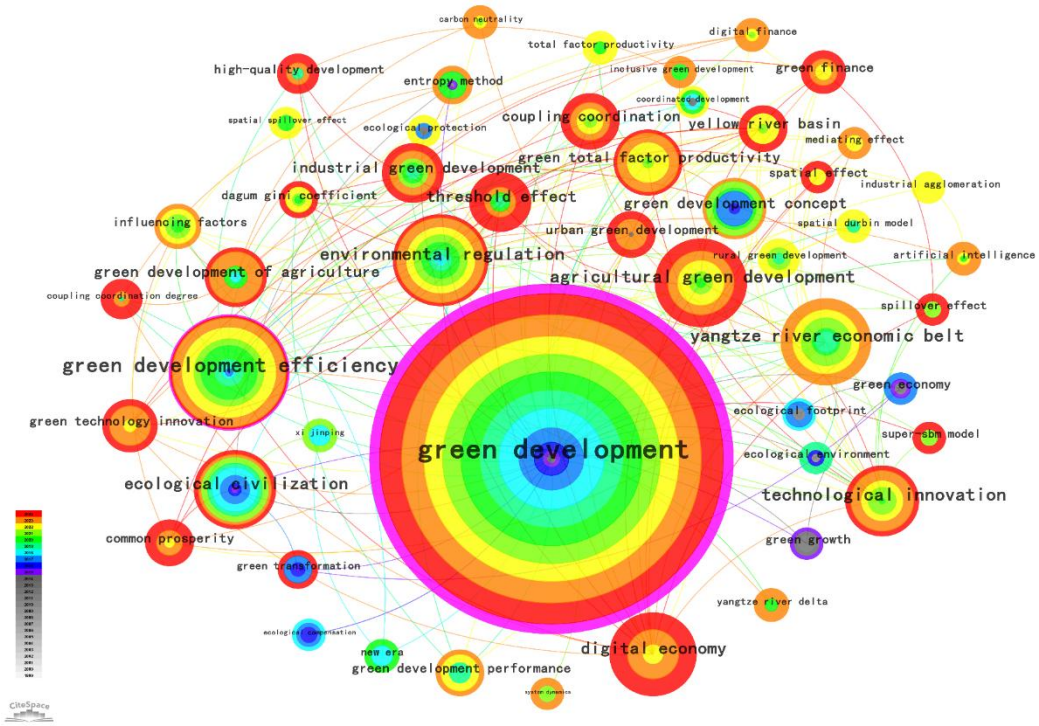

Figure 5. *Keyword co-occurrence network mapping*

A. Connotation of green development

Accurately understanding the connotation and characteristics of green development lays the foundation and provides a critical basis for effectively studying on its measurement and promotion pathways. Friberg and Hettne (1988) pioneered the concept of "green development", pointing out that it is an emerging development model constrained by both environmental capacity and resource carrying capacity, and that its development is driven by the level of industrial innovation. This viewpoint has gained widespread acceptance within the academic community, and has sparked significant discussions on addressing issues related to diminishing production factors, excessive environmental pollution, and the disappearance of the demographic dividend from an innovative perspective. Chinese scholars have also conducted research on green development from diverse disciplinary backgrounds and research objectives (Yang and Li, 2021). High-quality green development aims to shift China's economic growth from reliance on the expansion of speed and scale to reliance on improvements in quality and efficiency. It is imperative to promote economic development, to take the ecological environment and social governance into account, achieve integrated development across multiple domains, and establish a new pattern of harmonious coexistence between human beings and nature (Ren and Liu, 2019). Green development emphasizes a people-centered approach, recognizing the symbiosis and inseparability of human beings and nature, and asserting that human development must be grounded in profound respect for the objective laws of nature (Qiang and Jia, 2017). It represents an innovation-driven, high-quality, sustainable, and harmonious mode of development (Liu, 2017), embodying people's aspirations for a better life and serving as a critical strategy to effectively address issues of unbalanced and inadequate development (Wang and Hao, 2021). Achieving internal unity, mutual promotion, and coexistence between economic development and

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environmental protection is the core principle of green development (Zhu, 2020). The essence of green development is widely recognized by various institutions and scholars, despite differences in research perspectives and emphases concerning the concept. This lies in the fact that, under the constraints of resource scarcity and environmental degradation, green development aims to maximize resource use efficiency while pursuing the symbiotic development of the economy, society, and natural system through low-carbon and circular economic models.

B. Measurement of green development level

Green development is a significant initiative to achieve high-quality development and occupies a crucial position in the development strategies of most nations. Consequently, the measurement of green development level has drawn increasing attention from scholars. Research on measuring the green development level not only enables scholars and policymakers to gain a comprehensive understanding of the current state of regional green development but also assists them in exploring the influencing factors that hinder its enhancement and formulating differentiated countermeasures, which is essential for achieving the goal of green development. Lin et al. (2019) strictly confined the boundary of green development to the resource and environment dimensions, and used the super-efficient non-radial DEA model to measure the green index of the regional economic development in China, which evaluates the extent of resource consumption and the degree of environmental pollution in a region's economic development process. The calculation results show that the greenness of economic development is relatively high in the eastern regions, followed by the central regions, and relatively low in the western regions. Overall, the green development level still presents an unbalanced pattern among the eastern, central, and western regions, and the differences in the degree of greenness in economic development have further widened the gap in green development level between economically developed regions and underdeveloped regions. Zhu and Zhang (2019) analyzed the connotation of green development in the new era, constructed a green development evaluation index system, and applied the fixed-base range method for evaluation, with Guangxi as an example. The empirical results show that Guangxi's green development level exhibited an upward trend from 2009 to 2016; among the factors affecting green development, environmental quality, ecological protection, and environmental governance made significant contributions to Guangxi's green development, while resource utilization, growth quality, and green living indicators made relatively small contributions. Wu and Zhang (2022) introduced the potential effect coefficient to improve the extended C-D production function and subsequently established the green total factor productivity (GTFP) model to measure China's GTFP and its provincial levels from 2008 to 2019; the results indicate that China's GTFP showed an upward trend during this period. Specifically, the imbalance in China's regional GTFP remains relatively prominent: the contribution rate of inter-regional differences to the overall differences is relatively large but shows a narrowing trend, while the contribution rate of intra-regional differences is relatively small but presents an expanding trend. Moreover, China's provincial-level GTFP generally presents an overall pattern of "higher in the east and lower in the west" and "growing faster in the south and slower in the north". Zou and Han (2022) constructed an index for China's economy in the new era that aligns with the concept of ecological priority and green development. Their findings indicate that the green development level in developed regions is generally higher than that in less

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developed regions. Specifically, in terms of resource utilization and environmental protection level, the advantages of developed regions over less developed regions are relatively prominent, yet the gap between them shows a narrowing trend. Liu et al. (2019) constructed a green development index evaluation framework based on five dimensions: driving force, pressure, status, impact, and response, and comprehensively employed factor analysis, grey correlation analysis, and the Difference-in-Differences (DID) method for in-depth examination using panel data of 23 national ecological civilization demonstration cities in China from 2003 to 2015. The results of their study show that China's green development not only exhibits significant regional differences, but also such differences present a trend of structural solidification. Additionally, the promoting effect of policy tools such as the establishment of ecological civilization demonstration zones on green development has not yet been manifested. Therefore, this suggests that China's green development in the future should focus on improving efficiency and advancing technological innovation. Tian et al. (2022) evaluated the urban green development efficiency of 277 Chinese cities from 2010 to 2016 using the non-expected SBM model, examined their spatio-temporal patterns and city classifications, and investigated the causes of efficiency loss. The study finds that the overall level of urban green development efficiency in China remains relatively low, fluctuating downward before rebounding. Regionally, efficiency follows a pattern of Eastern > Northeastern > Western > Central. Environmental pollution, resource redundancy, and capital overstocking are identified as the primary causes of efficiency losses across all regions. Tian and Liu (2021) assessed the green development efficiency of Shaanxi Province and its 10 cities from 2001 to 2018, analyzing annual changes through calculations of the Global Malmquist index. The research results show that the overall green development efficiency of Shaanxi Province is at a moderately high level. From 2001 to 2018, the regions with high green development efficiency in Shaanxi Province gradually shifted from the northern to the southern parts, and showed a trend of polarization. Based on different research backgrounds and objectives, scholars have selected diverse evaluation methods, such as grey correlation analysis, the DID method, and the Slack-Based Measure (SBM) model, to quantitatively measure green development levels either through efficiency evaluations or comprehensive indicator analyses. Relevant studies have yielded targeted and empirically supported measurement results, which have revealed the regional disparities in green development levels and the core influencing factors of green development. These outcomes have not only provided diverse references for subsequent research on the construction of green development evaluation index systems, measurement methods, and data collection technologies, but also laid a theoretical foundation for measuring green development levels in a more comprehensive, accurate, objective, and scientific manner.

C. Influencing factors of green development

A pivotal component of green development research involves identifying its influencing factors, which not only reveal the underlying causes of fluctuations in green development levels but also elucidate these factors' mechanisms of action. This understanding provides a solid foundation for decision-making in forecasting future trends and formulating appropriate countermeasures. Most studies have used the panel Tobit regression model and spatial Durbin model to analyze these influencing factors. In general, green development is influenced by multiple driving forces at any given time. Guo et al. (2020) revealed that a "U-shaped" relationship exists between economic

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development levels and green development efficiency: with the ongoing increase in economic development levels, green development efficiency tends to initially decline before subsequently rising. Gai et al. (2022) concluded that economic development, international trade, and information communication significantly contribute to agricultural green development in the major grain-producing regions of Northeast China, whereas the level of industrialization exerts a notable inhibitory effect. By contrast, Mu et al. (2017) pointed out that economic foundation is a necessary but not sufficient condition for green development, as a region with a strong economic foundation does not necessarily exhibit a higher level of green development. In the aftermath of the international financial crisis, the global macroeconomy has exhibited a high degree of uncertainty, which has, to some extent, impeded the implementation of green development strategies. Sun et al. (2018) demonstrated that technological progress biased toward labor and capital may facilitate the establishment of local green economies, while the significance of human capital is increasingly recognized. Considering that industrial structure serves as the primary link between human economic activities and the natural environment, its rationalization and optimization can significantly drive regional-level green growth (Chen et al., 2018). From the perspective of industrial scale, a "U-shaped" relationship exists between regional green development efficiency and industrial agglomeration: as agglomeration increases, green development efficiency initially declines and then subsequently rises (Yue et al., 2015). Li et al. (2019) investigated the factors influencing green development efficiency by employing panel data from 105 prefecture-level cities in the Yangtze River Economic Belt and by applying the Tobit model. Their results indicate that improvements in green development efficiency are driven by economic agglomeration, investment in science and technology, increased openness to the outside world, and strengthened environmental regulation. Zhou et al. (2019) concluded that, from the perspective of the human-land relationship territorial system, human and social factors have a greater influence on urban green development efficiency than natural factors. Hao and Zhu (2019) concluded that technological innovation plays a part in fostering green growth and exhibits a spatial spillover effect, as revealed by analysis using the spatial Durbin model. Most studies have focused on the socio-economic dimensions of green development, including economic growth, scientific and technological innovation, industrial structure, and environmental regulations. These findings lay a solid theoretical foundation for formulating further countermeasures and recommendations aimed at enhancing the level of green development.

D. Transformation of green development

The Chinese government places significant emphasis on the transformation of green development and views its acceleration as an intrinsic need for China's development. This transformation has become a focal point for both government and academia. Various sectors are facing this transformation, yet there are no standard solutions or universally applicable roadmaps exist for achieving it (Li, 2016). Qi (2022) discussed the agricultural dimension of green development transformation from the perspective of the socio-economic-ecological system, and proposed a network-based approach that considers agricultural productivity, ecological effects, environmental equity, and social balance. Li (2020) pointed out that the transformation of green development for the marine economy necessitates enhancing the top-level design of the green system, reinforcing planning guidance and policy support, promoting marine eco-technological innovation, cultivating

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
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an ecological marine industrial system, facilitating the marketization of marine environmental resources, strengthening market-oriented green consumption, leading green financial innovation and sustainable supply chains, and ultimately driving the green growth of the marine economy. Yang et al. (2019) argued that accelerating industrial structural adjustment, promoting industrial greening through technological innovation, implementing the "three lines and one list" system (i.e., the red line of ecological protection, the bottom line of environmental quality, resource utilization caps, and environmental access lists), strengthening environmental regulations, perfecting environmental policies, and enhancing mechanism safeguards constitutes the pathway to facilitating the green transformation and upgrading of industries in Jiangsu coastal cities. For the transformation of green development on rural economy in China's economically developed regions, Wang (2021) suggested accelerating the integration of Internet technology with the rural economy, and vigorously supporting the construction of an agricultural science and technology innovation system guided by financial funds. Zheng (2019) believed that the transformation of green development represents a novel pathway for the revitalization of resource-depleted cities. Key countermeasures for green transformation are explored to address shortcomings of industry, talent, science, and technology by integrating into regional development, implementing categorized guidance for ecological restoration and reuse, forming new urban value spaces, and innovating multidimensional and multifaceted policy support. The transformation of green development should be implemented gradually, in accordance with the characteristics of a country's fundamental national conditions and its current stage of economic and social development. This transformation can be advanced through the establishment of a green production system, the promotion of green consumption patterns, the strengthening of market mechanisms, and the enhancement of green technological innovation capacity (Li and Li, 2013).

E. Institutional innovation for green development

As the world's second-largest economy, China's green development is bound to exert a profound influence not only on its future economic prosperity but also on global economic well-being. However, it is important to recognize that China still faces numerous challenges in sustaining green development, and further institutional innovations are still needed. The essence of green development lies in the transformation of the development model, which fundamentally depends on the support and driving force provided by a sound institutional system (Zhou, 2020). Green development institutions function as the social rules that guide and constrain individuals to coexist harmoniously with nature, which are continuously formulated and revised in response to a dynamically changing environment, and in turn, they shape the depth and direction of the green development process (She and Liu, 2018). It is essential to establish a green development target responsibility system to facilitate the formation of green supply patterns and green consumption patterns, and to build a modern, green, clean, and low-carbon energy system along with a resource recycling and reuse system (Wang et al., 2019). To enhance environmental governance capacity, it is essential to adhere to source control and whole-process management, implement cost-effective pollution control strategies, refine environment-related economic policies, and establish a collaborative multi-stakeholder regulatory mechanism involving the government, enterprises, and the public (Zhang, 2016). To promote the establishment of a green development safeguard mechanism, it is necessary to establish a green GDP evaluation system and optimize fiscal and tax policies

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
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for green industries (Tian, 2016). Furthermore, regarding systematic innovation in China's green development over the next three decades, it is recommended that such innovative design should adopt a strategically forward-looking perspective spanning 10–30 years, guided by the concept of the "ternary" life community that encompasses humans, robots, and the environment. This approach should advance high-quality innovation based on adjusted development planning goals while enhancing the precision and effectiveness of systems, policies, and measures (Liang, 2019).

F. Green development of agriculture

China's agricultural production plays a pivotal role in ensuring global food security. However, traditional agriculture is heavily dependent on the exploitation of natural resources and the environment, which not only undermines food security but also poses serious threats to sustainable development. Promoting the green development of agriculture is not only an inevitable choice for achieving high-quality agricultural development and modernization, but also constitutes a critical component of China's modernization path (Yin et al., 2021), one that emphasizes harmonious coexistence between humans and nature (Zhao and Zhou, 2024). Over the years, the No. 1 Central Document has consistently prioritized the green development of agriculture as one of its core tasks. The "*14th Five-Year Plan for the Green Development of Agriculture*" emphasizes establishing an agricultural system featuring green, low-carbon, and circular development, with the aim of comprehensively advancing the green transformation of agriculture. Since 2009, China's agricultural green development index has steadily improved; however, significant inter-provincial disparities persist, and a certain gap remains when compared to international standards (Liu et al., 2025). While a solid foundation exists for promoting green agricultural development in the new era, challenges remain, including a shortage of modern agricultural talent, insufficient scale expansion, slow digital transformation, and considerable gaps in scientific and technological innovation (Qu and Xi, 2025). The green development of agriculture results from the combined influence of multiple interrelated factors, and no single factor can independently serve as a sufficient condition for achieving high-level green agricultural development. Technological conditions, including productivity levels, digitalization levels, and scientific and technological innovation capacities, serve as the primary driving forces for advancing the green development of agriculture (Sun et al., 2024). By prioritizing the enhancement of advanced agricultural technology applications, accelerating the development of agricultural industrial, production, and management systems, and further refining the market-oriented green technology innovation system, we can effectively promote the sustainable agricultural development (Zhang et al., 2025).

Analysis of research frontiers

The research frontier not only reflects the new progress and trends of scientific research, but also reveals the innovative, growing, and interdisciplinary topics in the research field (Wu et al., 2015). By applying the keyword burst detection function of CiteSpace to process the data, we can observe the evolution of green development over the years and identify the research frontiers. In particular, γ [0, 1] in the Burstness function is set to 0.1, and Minimum Duration is set to 1, 25 burst keywords in China's green development research were detected (*Table 1*).

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2306_1135911386

Table 1. *Top 25 keywords with the strongest citation bursts*

Keywords	Strength	Begin	End
low carbon economy	2.01	2009	2011
green economy	2.50	2012	2017
green growth	2.49	2013	2015
ecological civilization	4.54	2014	2018
green transformation	2.50	2015	2017
ecological compensation	2.02	2016	2018
the belt and road	1.82	2019	2019
influencing factors	2.00	2020	2022
green development level	1.79	2020	2020
restricted development zone	1.79	2020	2020
technological innovation	2.88	2021	2024
yangtze river economic belt	2.60	2021	2024
coupling coordination	2.46	2021	2024
yellow river basin	2.20	2021	2022
rural green development	1.94	2021	2022
digital economy	8.03	2022	2024
green total factor productivity	3.77	2022	2024
green technology innovation	3.44	2022	2024
common prosperity	2.58	2022	2024
industrial agglomeration	2.29	2022	2022
green finance	2.29	2022	2024
manufacturing agglomeration	1.72	2022	2022
urban green development	2.99	2023	2024
green development of agriculture	2.54	2023	2024
coupling coordination degree	2.17	2023	2024

The keywords with the strongest citation bursts (*Table 1*) reflect the evolving thematic distribution of green development research across different time periods. The distribution of keywords continues to evolve as time progresses. In the early stages, there were fewer keywords, but as time goes on, the keywords became increasingly diverse, reflecting the continuous expansion and deepening of the field. In recent years, keywords such as “green total factor productivity”, “green finance”, “green technology innovation”, “digital economy”, “yangtze river economic belt”, “coupling coordination”, “urban green development”, “green development of agriculture”, and “common prosperity” have become the focuses. The in-depth exploration of these topics has established the current research frontiers. Total factor productivity (TFP) is inadequate for providing a comprehensive and meaningful assessment of economic development quality, as it overlooks critical factors such as pollution emissions and ecological impacts. In contrast, GTFP comprehensively integrates undesirable outputs, such as pollution emissions and ecological considerations, thereby aligning more closely with the contemporary concept of green development (Li et al., 2015). With the evolution of green development, green finance has emerged as a significant measure to support the reforms of China’s economic structure, investment structure, and industrial structure (Ma, 2018). Industrial upgrading is driven by green technology innovation,

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which highlights the pivotal role of green development in advancing environmental governance and fostering sustainable economic growth (Si, 2019). The digital economy not only functions as a pivotal driver for industrial transformation, upgrading, and developing innovative business models but also represents a strategic breakthrough for addressing the dual challenges of resource constraints and growth bottlenecks, thereby advancing the green transition of the economy (Wei and Hou, 2023). Meanwhile, green development reciprocally enhances the development of the digital economy, indicating a coupled coordination relationship between the two (Ji and Liu, 2024). The Yangtze River Economic Belt encompasses nine provinces and two municipalities, accounting for a large share of China's total economic output and constituting one of the three key national spatial development strategies in China. Since the implementation of the strategy for conservation and prohibition of over-development along the Yangtze River, all relevant parties have actively promoted ecological restoration and the transition to green development. Consequently, green development in this region has demonstrated positive momentum (Duan et al., 2022). The green development of agriculture not only ensures food security, boosts rural economic prosperity, and sustains ecological harmony but also reflects the contemporary necessity for a fundamental transformation of the agricultural development model. This transition is driven by human society in its response to escalating resource and environmental constraints, as well as the intensifying challenges posed by climate change. Eradicating poverty and attaining common prosperity represent the shared aspiration of humanity and constitute one of the objectives to be achieved through green development. Efforts should be directed toward advancing the green development agenda, establishing a harmonious relationship between human society and the natural environment, sustaining the growth of the green economy, and ultimately achieving common prosperity. Systematic investigation and analysis of the aforementioned issues have emerged as the frontiers in the field of green development.

Diversified practices of facilitating China's green development

The collected grey literature and policy documents not only outline the current status of China's green development but also provide essential supplementary information for academic research. In 2015, China formally introduced the concept of green development for the first time. Since then, China has actively implemented this concept and developed a range of diversified practices.

China actively fosters and advances the development of emerging green industries. First, China's renewable energy industry has developed rapidly. China has made great efforts to develop renewable energy industries such as wind power, solar energy, and biomass energy to optimize the energy structure. By the end of 2024, the nationwide installed capacity of renewable energy reached 1.889 billion kW, representing a year-on-year increase of 25% and accounting for approximately 56% of the nation's total installed capacity. Specifically, the installed capacities were as follows: hydropower at 436 million kW, wind power at 521 million kW, solar power generation at 887 million kW, and biomass power generation at 46 million kW (China National Energy Administration, 2025). Second, China's new energy vehicle (NEV) industry has experienced robust development. By the end of 2024, the production and sales of NEVs reached 12.888 million units and 12.866 million units, respectively, with year-on-year growth rates of 34.4% and 35.5%. Notably, NEV sales accounted for 40.9% of the total sales of new cars, highlighting the significant penetration of NEVs in the automotive market (People's

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Daily, 2025). China remained the world's largest NEV market for the 10th consecutive year, with production and sales exceeding 12 million units in 2024 (Global Times, 2025). Third, China is proactively advancing the development of green buildings. By employing key strategies such as energy-efficient design, utilization of renewable energy, and innovation in environmental protection materials, green buildings have transitioned from conceptual exploration to large-scale implementation. As of the end of 2023, the cumulative floor area of green buildings constructed in urban areas nationwide reached approximately 11.85 billion square meters. In particular, the floor area of newly constructed green buildings in urban areas throughout 2023 was about 2.07 billion square meters, accounting for 94% of the total newly built floor area in urban regions (China Construction News, 2024).

China is advancing the green transformation of traditional industries through targeted policies and technological innovation. In 2022, the Ministry of Ecology and Environment (MEE) and other relevant departments jointly issued the *Implementation Plan for Carbon Peak in the Industrial Sector*, which clearly outlined a transformation pathway focused on technologies like hydrogen-based smelting and carbon capture, utilization, and storage. By 2024, leading enterprises like Baowu Group had successfully established hydrogen metallurgy demonstration lines. This initiative aligns with the *Cleaner Production Promotion Law*. At the industrial park level, promote intensive and sustainable transformation by adopting models such as eco-industrial parks and circular economy demonstration parks. By 2024, a total of 491 national-level green industrial parks have been cultivated throughout China.

China actively advances the development of the circular economy. As a crucial component of green development, the circular economy has been seamlessly integrated into the strategic framework of China's economic transformation. Driven by iterative upgrading of the policy system and innovative breakthroughs in industrial practices, China has developed a distinctive circular economy model. In 2023, the resource recycling industry reached a scale of 4.077 trillion yuan (CCID Consulting), representing a year-on-year increase of 13.1% (Economic Daily, 2024). Since the circular economy was officially integrated into the national strategy at the 2004 Central Economic Work Conference, the Chinese government has introduced a series of policies and institutional frameworks to advance its development. In 2005, the *Several Opinions of the State Council on Accelerating the Development of the Circular Economy* officially established the guiding principles of "reduction, reuse, and recycling". In 2008, the *Circular Economy Promotion Law* was enacted, institutionalizing key mechanisms such as the extended producer responsibility system. In 2021, two landmark documents were released: the *Guiding Opinions on Accelerating the Establishment and Improvement of a Green, Low-Carbon, and Circular Development Economic System* and the *14th Five-Year Plan for the Development of the Circular Economy*. In 2024, the *Opinions of the General Office of the State Council on Accelerating the Establishment of a Waste Recycling System* was issued, putting forward that establishing a waste recycling system is an important measure for implementing the comprehensive conservation strategy (General Office of the State Council, 2024). These documents outlined a new paradigm for the circular economy aligned with the "dual carbon" goals.

China's green development model

With the advancement of the global sustainable development agenda, green development has emerged as a core concept and national strategy propelling the high-

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quality development of China's economy and society (Liu and Wu, 2024). Through years of continuous exploration and practice, China has gradually developed a distinctive green development model. This model is multidimensional and integrated, characterized by policy guidance as its orientation, market mechanisms as its driving force, multi-stakeholder governance as its foundation, technological innovation as its means, and legal frameworks as its cornerstone. Not only has this model facilitated a profound transformation of China's economic and social development pathways, but it has also contributed valuable Chinese experiences to the global green development agenda (*Fig. 6*).

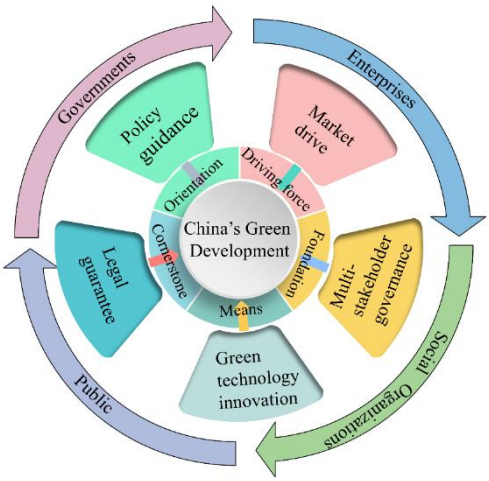

Figure 6. *China's green development model*

Policy guidance is the primary characteristic of China's green development (Guo et al., 2020). The Chinese government has positioned green development as a crucial national development strategy. By implementing robust top-level design, systematic strategic planning, and targeted policy support, it provides clear directional guidance and actionable guidelines for advancing green development. In practice, the government has been continuously refining the green development policy system and has established a three-level policy framework characterized by "central-level overall planning, inter-ministerial coordination, and local implementation". Market drive is an important internal impetus for China's green development (Gong and Dai, 2021). While reinforcing policy guidance, greater emphasis is placed on leveraging the driving force of market mechanisms for green development. By establishing and refining a comprehensive, multi-level green market system and mechanism, the intrinsic motivation of market entities can be activated, thereby facilitating the optimal allocation of environmental resource factors. Green development is a complex and systematic endeavor that necessitates the collaborative participation and coordinated governance of multiple stakeholders, including governments, enterprises, social organizations, and the public (Fu and Geng, 2019). Since the 18th National Congress of the Communist Party of China, a new paradigm of environmental governance has gradually taken shape, featuring government leadership, enterprises as the primary actors, and the joint participation of social organizations and the public. This has fostered a positive pattern in which the entire society collaboratively advances green development. Technological innovation is the core engine driving China's green development (Luo et al., 2019). The government places

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emphasis on green technological innovation, continuously facilitating research and development (R&D) and the transformation of green technologies, which provides critical support for low-carbon transformation and green development. Legal guarantees form a critical cornerstone of China's green development. The country has gradually built a four-tier legal system for ecological and environmental protection, comprising the Constitution, laws, administrative regulations, and local regulations. Furthermore, it has continuously strengthened the enforcement of environmental rule of law, providing standardized and institutionalized safeguards for the steady advancement of green development.

Challenges and prospects of China's green development

The preceding section has elaborated on China's green development model. However, despite remarkable progress in green development, China still faces a set of significant challenges. Drawing on relevant research findings and grey literature, this study identifies four key challenges and outlines prospects for optimizing the pathways to promote China's green development going forward.

A. Significant pressure for the transformation of the energy structure

Energy serves as a critical driving force and material foundation for the development of human society and the economy (Song et al., 2022). Yet despite its pivotal role, the transformation of the current energy structure remains fraught with significant challenges. From the perspective of energy composition, China's energy endowment is characterized as "abundant coal, limited oil, and scarce natural gas", which has resulted in fossil fuels, particularly coal, dominating primary energy consumption, even as their proportion has gradually declined (Jin, 2018). This coal-intensive energy structure remains the primary factor to carbon dioxide emissions in China. Although China has emerged as the world's largest investor, producer, and consumer of renewable energy, the share of new renewable energy sources such as wind and solar power in primary energy consumption remains relatively low.

Optimizing the structure of energy production and consumption, alongside improving the overall energy utilization efficiency, represents the core pathway for China to promote a systematic transformation of its energy system. This process necessitates coordinated efforts from both the supply and demand sides. Given "abundant coal, limited oil, and scarce natural gas" resource endowment, strategic and proactive national planning should be implemented to deeply adjust the energy structure, thereby accelerating the transformation of the energy system.

B. Bottleneck in green technology innovation

Among the core elements of green development, the supporting role of green technologies is pivotal. As a developing country, China still faces structural gaps in green technology innovation. This is primarily reflected in three aspects: inadequate accumulation in basic research, limited capacity for original innovation in cutting-edge technologies, and the "neck-stuck" challenge faced by key core technologies. This technological dependence not only hinders the enhancement of industrial competitiveness but also poses potential risks to energy security and the progress of green transformation. To address these challenges, strengthening independent innovation in green technologies is imperative.

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
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The government should establish a targeted specialized support system for green technology innovation and implement preferential policies tailored to resource allocation such as financial capital and talent cultivation. This will foster a stable and predictable policy environment, encouraging innovation actors (e.g., enterprises, research institutes) to concentrate on securing critical technological breakthroughs. High-level research institutions should be supported to tackle key scientific challenges in basic research. Leading enterprises should be encouraged to establish green technology innovation alliances, facilitating collaborative R&D among industry, academia, research institutions, and end-users. Fragmented innovation resources should be consolidated to build a cohesive and comprehensive innovation ecosystem covering the entire chain: from "basic research" to "applied development" and onward to "industrial transformation." It is essential to fully leverage the enabling role of digital technology in four key areas: energy consumption control, energy substitution, innovation matching, and technology scaling. This will accelerate the iteration cycle of green technologies and improve the precision of green technology innovation (Wei and Hou, 2023).

C. Imbalance in green development among regions

Green development is closely tied to technological innovation capabilities, industrial synergy levels, and resource endowments. While government's series of regional coordinated development strategies have narrowed regional development gaps, the disparities in green development remains pronounced. From the perspective of China's four major regions (Eastern, Central, Western, and Northeastern), the Eastern region takes the lead in the application of green technologies, as well as industrial structure optimization. In contrast, the Central and Western regions face constraints due to their heavy reliance on traditional energy sources and path dependence in industrial development, which hinders the transformation of resource-dependent cities and results in relatively low GTFP. The Northeastern region confronts dual challenges: industrial decline and ecological restoration. Despite its high forest coverage rate, the region faces challenges stemming from inadequate investment in green technology innovation and a below-average adoption rate of green agricultural technologies compared to the national average.

As a large developing country, China exhibits substantial regional differences in resource endowments, cultural traditions, and industrial structures. Given these realities, regional modernization cannot follow a one-size-fits-all approach; instead, green development pathways must be tailored to local conditions (Han and Lan, 2023). The Eastern region should leverage its strength in agglomerating innovative factors, prioritize cultivating zero-carbon and negative-carbon technology industries, take the lead in breaking through emission reduction institutional mechanisms such as carbon pricing and emissions trading systems, and further enhance the nationwide dissemination of green and low-carbon efficiency. The Western region should capitalize on opportunities from the Belt and Road Initiative and the strategy of opening up. The Northeastern region, it is essential to fully leverage its ecological and agricultural resource advantages, strengthen the construction of a national ecological security barrier, and accelerate the adoption of green agricultural technologies. The Central region should capitalize on its geographical advantage of linking the Eastern and Western regions, and its robust manufacturing foundation to facilitate the green, low-carbon, and circular transformation of industries, and construct an internationally competitive green intelligent manufacturing hub.

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D. Insufficient promotion of green lifestyles

Although the overall environmental quality in China has improved, the per capita carbon footprint continues to rise, highlighting the urgency of promoting low-carbon production and lifestyles (Pan and Zhang, 2021). Green lifestyles have been increasingly integrated into people's daily life in China, effectively driving the transformation of the industrial economy and energy structure towards sustainability through demand-side reforms. Nevertheless, from a long-term perspective, further advancement of green lifestyles still faces numerous practical challenges. On the one hand, public awareness of green lifestyles remains insufficient, with insufficient internal motivation and proactive awareness to engage in low-carbon behaviors. On the other hand, the public's understanding of green and low-carbon consumption is constrained by knowledge gaps. Specifically, individuals lack a comprehensive understanding of key concepts such as carbon footprint and environmental certification, causing their consumption patterns to fall short of the requirements for green transformation.

To facilitate the widespread adoption of green lifestyles, it is essential to establish a three-dimensional promotion framework encompassing "concept cultivation, consumption guidance, and technology empowerment". First, it is necessary to deepen multi-dimensional education on green development by fully integrating the principles of low-carbon living, environmental sustainability, and ecological civilization into family, school, and societal education systems. This will enhance the dissemination, understanding, and practical application of environmental knowledge, laying a solid cognitive foundation for green behaviors. Second, new media platforms such as Kwai, WeChat, and Weibo should be utilized to advocate for green and low-carbon consumption concepts and encourage sustainable consumer behaviors. Through these channels, promote the sharing economy and circular economy while advocating for a frugal, green, civilized, and healthy lifestyle and consumption model. Third, technology innovation should be harnessed to support green living. For instance, develop smart appliances and green buildings to enable precise energy consumption control; establish personal carbon accounting systems to quantify low-carbon behaviors; and use digital tools to convert abstract environmental protection concepts into concrete, actionable, measurable, and incentive-driven practices.

Discussion

Green development serves as a core concept and crucial pathway for China to harmonize economic growth with ecological environmental protection. Over time, China has gradually explored a distinctive green development path with Chinese characteristics, evolving from passive pollution control to active ecological conservation, progressing to systematic green transformation, and ultimately advancing to coordinated promotion. Through a bibliometric analysis and systematic review of green development research in China, this study examines the theoretical research outcomes and practical progress of this field.

However, it should be noted that this study searched the Chinese database but did not include international databases such as Google Scholar or Web of Science. This design was primarily based on the core objective of this review: to conduct an in-depth synthesis and focus on the research trajectory and practical experiences of green development within China's unique local context. Chinese databases represent the most comprehensive and concentrated sources for such literature, as they contain a wealth of local cases, policy interpretations tailored to China's context, and research addressing the unique

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characteristics of China's green development content that is not fully covered by international literature. Therefore, prioritizing the use of Chinese databases ensures that the complexity and particularity of China's green development research can be deeply captured, which is the most direct and effective approach to achieving the study's objectives.

Notwithstanding this limitation, this study does suggest that future work will expand the research scope, and conduct a comparative analysis of this findings with a broader body of international literature focusing on comparisons in research perspectives, methods, and conclusions, which will facilitate a more integrated global theoretical framework for green development.

Conclusions

China has achieved significant progress in both theoretical research and practical exploration of green development. This paper analyzes the spatio-temporal distribution, research hotspots and frontiers of China's green development, and summarizes the diversified practices that facilitate its advancement. Based on a comprehensive review of existing literature and current practices, this study elucidates the China's green development model and pinpoints four major challenges facing this field.

We find that: First, the number of publications related to green development in China has shown an obvious upward trend from 1999 to 2024, indicating that green development is a hotspot in current academic research. According to the characteristics of literature distribution, the growth in publications has experienced initial germination phase, exploratory rising phase, and vigorous developmental phase, which benefits from the promotion of national policies, the demand of realistic development, the increase of green investment, and the advancements in green technology innovation. Second, in terms of journal distribution, core journals publishing green development-related research span multiple disciplines, including economics, geography, and philosophy, reflecting widespread interdisciplinary interest. Third, research hotspots in China's green development focus on six aspects: connotation, measurement, influencing factors, institutional innovation, transformation, and green development of agriculture. Finally, the research frontiers of China's green development include green finance, green technology innovation, and green total factor productivity, etc. Additionally, based on the literature and ongoing practices, this study elaborates on the green development model, and further illustrates four major challenges: significant pressure for the transformation of the energy structure, bottleneck in green technology innovation, imbalance in green development among regions, insufficient promotion of green lifestyles.

China's green development is currently in a pivotal transition phase, shifting from "policy-driven" to "innovation-driven". Although challenges such as the lock-in effect of the existing energy structure, regional disparities, and technological bottlenecks persist, a multi-level promotion framework has been established. Guided by the "dual carbon" goals, this framework fosters market-based mechanism innovations, supports independent technological breakthroughs, and actively participates in global governance. Moving forward, it will be essential to address issues such as the high transformation costs faced by small and medium-sized enterprises (SMEs) and the inadequacies of regional coordination mechanisms. Simultaneously, it is important to seize new growth drivers such as the new energy industry, digital technologies, and green finance, thereby contributing a "Chinese solution" to global sustainable development.

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