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EDITED BY
Fengtai Zhang,
Chongqing University of Technology, China

REVIEWED BY
Xiaochun Zhao,
Anhui University, China
Chen Li,
Shanghai University of Engineering Sciences, China

*CORRESPONDENCE
Chaoyang Li,
17615706604@163.com

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Digital industry agglomeration and inclusive green growth: Synergies and path exploration

Ke Lu[1], Yifei Qiu[1], Jialin Zhang[1], Chaoyang Li[2]* and Jinkai Xie[3]

[1]Business School, Shandong University of Technology, Zibo, China, [2]School of Economics and Management, Weifang University of Science and Technology, Weifang, China, [3]School of Economics and Management, Langfang Normal University, Langfang, China

One crucial tactical choice to accomplish high-quality economic development in China is to advocate for inclusive green growth, stimulate green and shared growth, and help achieve common prosperity for everyone. Based on the theory of endogenous economic growth and from the perspective of resource allocation and technological innovation, this paper uses China's provincial panel data from 2012 to 2023 to systematically explore the impact mechanism and spatial heterogeneity characteristics of digital industry agglomeration on inclusive green growth through fixed effect model, mediating effect model, and threshold model. The analysis concludes that: (1) Digital industry agglomeration greatly facilitates inclusive green growth. For every additional unit of digital industry agglomeration, inclusive green growth will increase by 0.215 units. (2) Regression analysis based on regional heterogeneity, the effect was manifested as the trend of "Western region > Central region > Eastern region". (3) The analysis of the transmission mechanism shows that resource allocation efficiency and technological innovation constitute the core intermediary path. Assuming that all other variables stay constant, each unit change in the resource allocation efficiency will significantly increase inclusive green growth by 0.055 units. For technological innovation, for every 1 unit change in digital industry agglomeration, it will indirectly promote an increase of 0.013 units in inclusive green growth. (4) Based on provincial heterogeneity, digital industry agglomeration has threshold effects on inclusive green growth. At the initial stage of digital industry agglomeration, it plays a substantial role in facilitating inclusive green growth. When the resource allocation efficiency does not reach the threshold of 0.8394, moderately improving the resource allocation efficiency can enhance the effect of regional digital industry agglomeration and significantly improve the benefits of regional inclusive green growth. In particular, every 1 unit change in digital industry agglomeration encourages inclusive green growth by 0.874 units. When the threshold variable is considered technological innovation, it has a key inflection point of 10.1339. After crossing the threshold, the regional development model changes from competitive "beggar neighbor" to cooperative "neighbor as a partner". The research conclusion offers reference value for fostering a favorable atmosphere for digital sector expansion and inclusive, sustainable green growth.

KEYWORDS

digital industry agglomeration, resource allocation efficiency, technological innovation, inclusive green growth, mediating effect, threshold regression

1 Introduction

The goal of *the Third Plenary of the 20th CPC Central Committee* was to "further comprehensively deepen reform and advance Chinese-style modernization," striving to accomplish the full development of economic, social, and ecological civilization by further emancipating and developing productive forces, advancing social justice and fairness. The procedure of urbanization and industrialization is progressing swiftly in the setting of rapid economic expansion, and human standards of living keep growing better. However, it is accompanied by unbalanced and uncoordinated economic development and the increasingly prominent problem of sustainability (Cui et al., 2024). Specifically, on the one hand, the broad development mode with high input, high consumption, high pollution, and low efficiency has contributed to resource depletion, environmental pollution, and ecological damage (Mishra et al., 2024). The *Emissions Gap Report 2023* was released by the United Nations Environment Program (UNEP), which stated that the G20 countries' greenhouse gas emissions climbed by 1.2% in 2022, comprising 76% of the worldwide total emissions, with the United States, China, and the European Union generating the most significant contributions. On the other hand, throughout economic expansion, there are uneven growth opportunities, unfair sharing of fruits, and a growing disparity in income, with urban-rural residents' incomes being 2.56:1 in 2022, and social inequality will be intensified. These issues stem from the conventional expansion mode's lack of "green" and "inclusiveness". To this end, per the report of *the 20th National Congress of the Communist Party of China*, China is dedicated to accomplishing the objectives of "improving people's livelihood" and "promoting green development" in the future by putting in place several ecological protection and restoration projects, establishing a contemporary development model of peaceful coexistence between humans and nature with inclusive green growth (hereinafter referred to as *Ingreen*), and strengthening the ecological civilization system, to guarantee that everyone benefits from development in a more environmentally friendly setting.

The rapid development of globally competitive digital industrial clusters is a crucial driver of regional economic expansion, as a result of swift growth and utilization of digital technology, including digital twins and artificial intelligence. The digital economy, which is focused on inclusive and environmentally friendly development, has emerged as an essential engine for exceptional development in contemporary times. The digital industry has progressively emerged as a new engine to support inclusive economic growth and a new driving force to boost the potential of green development as a consequence of the digital economy's spectacular rise (Shen et al., 2019). Existing studies show that digital technology enterprises tend to concentrate in areas with well-developed digital infrastructure and dense talent reserves, and their agglomeration effect is not only reflected in the concentration of physical space (Ciarli et al., 2024), but also boosting the dependence on the cross-domain circulation of data pieces and the network effect of digital platforms (Goldfarb and Tucker, 2019). However, the measurement of digital industry agglomeration (hereinafter referred to as *Digagg*) still faces challenges. Traditional indicators such as enterprise density or employment concentration make it difficult to capture the intangible capital investment in digital technology (Chen and Hu, 2022). Some scholars have attempted to combine patent text mining technology to identify agglomeration dynamics through the spatio-temporal distribution of digital-related patents. It is worth noting that the high R&D investment in the early stage of the digital industry may lead to the "agglomeration paradox", which requires research to distinguish the agglomeration effects at different stages. The agglomeration effect and knowledge spillover effect of digital industries can benefit a wider group, especially in resource-rich regions. Through energy conservation, emission reduction, and resource recycling, China is capable of ensuring that the advantages of economic progress are distributed fairly among all societal sectors and assist in resolving several issues, particularly social inequality and environmental degradation. At present, the literature on *Digagg* mainly focuses on technological innovation (hereinafter referred to as *Inno*) and economic efficiency (Yuan et al., 2023; Xin, 2023; Jiao et al., 2023). A few researchers have delved into how *Digagg* affects *Ingreen*. Given the circumstances, China urgently needs to board the "high-speed train" of the digital economy's development to accelerate the promotion of *Ingreen* and solve the issue of traditional extensive growth's lack of "inclusive" and "green" characteristics (Jiang and Liu, 2024). In this process, *Digagg* are expected to become a key force driving *Ingreen*.

In light of the above, this study primarily examines the following questions: Is *Digagg* destined to be a major factor in *Ingreen*'s success? If the response is in the affirmative, what is the transmission mechanism through which *Digagg* influences *Ingreen*? Furthermore, do the "inclusiveness" and "greenness" of the digital sector provide special laws and features depending on China's regional heterogeneity? Analyze the role of *Digagg* on *Ingreen*, establish its unique role in promoting the process, and formulate precise policies.

The purpose of this essay is to examine how *Digagg* affects *Ingreen*. This paper's potential marginal contributions include: First, the present research broadens the study of the green economy impact of industrial agglomeration by methodically analyzing the influence of *Digagg* on *Ingreen* and its process, and deepens the understanding of the inherent law of digital empowerment affecting pollution and carbon reduction. Through systematic research, the key influencing factors of *Digagg* in the process of promoting *Ingreen* are revealed, which offers a conceptual framework for creating more focused green development policies. Secondly, to ensure the objectivity and rigor of the indicators and improve the simplicity of the indicator system in actual operation, after fully considering the practical significance of each indicator, this paper comprehensively constructs *Ingreen* indicator system from four dimensions. *Ingreen* is precisely measured utilizing the projection pursuit model, which is based on the actual coding accelerated genetic algorithm. Thirdly, this study focuses on the resource allocation efficiency (hereinafter referred to as *Resource*) and *Inno* in the process of *Ingreen*, attempting to uncover the intricate mechanism underlying *Digagg*'s influence on *Ingreen*. Through in-depth analysis, this paper aims to clarify how *Digagg* can promote the *Ingreen* of the economy by optimizing *Resource* and promoting *Inno*. Finally, based on the characteristics of provincial heterogeneity, the quadratic connection between *Digagg* and *Ingreen* is further examined in the present study and concludes that optimizing the layout of the digital sector can encourage collaboration and integrated growth across different regions, as well as offer theoretical support for accelerating the transformation of China into a green and sustainable development country.

This is how the remainder of the paper is structured: The second part examines *Digagg*, its impact on *Ingreen*, and relevant research related to *Ingreen*. The third section expounds on the paper's theoretical analysis and research hypothesis. The model construction, measurement and description, and data source are all discussed in section four. The fifth section presents the verification and analysis of the empirical results. Lastly, we present the research summary, academic value, policy implications, and limitations of this paper.

2 Literature review

2.1 Relevant research on *Digagg*

As an emerging business form, the digital economy industry grows with the national digital and information strategy, and technology and market promote its connotation and extension. The classification of the digital industry in the *White Paper on the Development of China's Digital Economy (2020)* has received widespread acknowledgment from the academic community. (1) Variable measurement. Industrial agglomeration has formed amount of research results in the academic circle, and its measurement methods include spatial Gini coefficient, industry concentration, Herfindahl index, location entropy, etc (Li et al., 2024a). Most of the existing measurements of *Digagg* are according to the municipal and provincial levels. The category of digital industry obtained by combining the definition of digital industry by the CAICT with the research theme is measured by using the locational entropy index, which can avoid the impact of regional-scale differences and reflect the industrial distribution of regions of different sizes. (2) Driving factors. The benchmark regression model and the mediating effect model have been employed by numerous researchers to investigate the impacts, either direct or indirect, of the degree of scientific and *Inno* (Zang et al., 2025), data element construction (Zhang L. Y. et al., 2024), technology accumulation (Rudy and Hector, 2023) on *Digagg*. Among them, the importance of the data factor in market construction cannot be ignored. It not only realizes the "self-value-added effect" of the digital sector but also encourages the "integration value-added effect" between the digital sector and other sectors. (3) Influence effects. The digital industry in a particular area can successfully overcome temporal and spatial constraints and show significant spillover effects of space, technology, and knowledge. The factors such as data resources and talents of these clusters are not limited to their local role, but can also promote the surrounding economic development. Within the region, the diversity of clusters has a positive effect on digital innovation, especially for highly digitized SMEs, and knowledge spillover is particularly obvious (Choi and Park, 2024). *Inno* is mainly realized in the agglomeration area through data capital and technology spillover (Yuan et al., 2023).

2.2 Relevant research on the impact of *Digagg* on *Ingreen*

According to current research, *Ingreen* is a sustainable development approach that aims for economic growth. This definition is based on studies on the extension and meaning of the term, environmental friendliness, and social equity (Fan et al., 2023). Therefore, the impact of *Digagg* on *Ingreen* can be expanded from the above three levels.

Firstly, while some researchers conducted an empirical study, the majority of pertinent studies on *Digagg*'s effect on economic growth concentrate on the theoretical level. On the one hand, theoretically, researchers have confirmed *Digagg*'s beneficial contribution to local economic development. The benchmark regression approach has been employed by numerous researchers to examine the effects of *Digagg* on regional economic resilience (Qi et al., 2025), green economic growth efficiency (Xin, 2023; Jiao et al., 2023), and new quality productivity (Zhou et al., 2024; Wu et al., 2024), concerning the way economic progress affects. In light of this, it is generally accepted that China's economic expansion has benefited tremendously from its expansion of the digital sector. With the "Belt and Road" being implemented in its entirety, all countries should enhance cooperation on digital infrastructure (Yang and Shi, 2021). Countries should strengthen cooperation on digital infrastructure and develop digital industry clusters. To encourage the creation of a new pattern of economic development, the region should also hasten the expansion of the digital economy sector and provide new momentum for China's economic advancement (Lu, 2021). On the other hand, A few academics have additionally examined *Digagg*'s effect on *Ingreen* quantitatively. On a macro level, Yasmeen et al. (2024) focused on the degree of economic growth and confirmed, through the creation of an SDM model, the positive impact of industrial agglomeration on the standard of regional economic development, and this agglomeration trend would inhibit the development of neighboring regions. From the standpoint of industry level and city scale, according to various academics, the urban economic efficiency benefits from industrial agglomeration ought to initially develop and afterward diminish as the degree of agglomeration grows (Smetkowski et al., 2021). Therefore, *Digagg* in major urban agglomerations in China is likely to contribute to increasing the efficiency of economic growth.

Secondly, it is possible to examine *Digagg*'s adverse effects on environmental friendliness from a micro as well as a macro perspective. At the macro level, *Digagg* was crucial to the advancement of technologies for treating pollution and the expansion of governance services, which promoted the efficiency improvement and green transformation of the urban green economy (Jiang and Chen, 2024). At the micro level, the power of *Digagg* has stimulated the restructuring and innovation of the industrial chain, thus giving rise to a succession of new industries and new kinds of business, making the industrial structure evolve in a greener, more productive and intensive path, promoting the intensification of production methods (Hunjra et al., 2024), and giving regional economic development a fresh lease on existence. Under this development trend, the region will attain a scenario where environmental preservation and economic expansion are mutually beneficial.

Thirdly, the impact of *Digagg* on social equity can be analyzed from two aspects: the equality of development opportunities and the equitable sharing of development outcomes. From the perspective of equal development opportunities, while encouraging the slow transition of conventional sectors toward digitalization, the penetration of digital industry realizes the development of *Digagg*, creates a large number of jobs, can consistently take in a significant amount of fresh personnel in society, accelerate the process of common prosperity (Hu and Li, 2019). At the same time, information and data sharing brought about by the Internet revolution will, to a certain extent, alleviate the information asymmetry faced by migrant workers, youth groups, low-skilled workers, and other disadvantaged groups in employment. From the perspective of development achievement sharing, *Digagg* strengthens the improvement of digital infrastructure, thus encouraging the development of a platform for network sharing to connect cities and rural areas, promoting the free movement of urban and rural manufacturing components to rural areas with the goal to reduce the gap between the two.

2.3 Relevant research on *Ingreen*

China's economic growth has changed from an explosive growth phase to a high-quality growth phase, and inclusive green development has become an inevitable choice for economic, social, and resource, and environmental coordinated development. *Ingreen* was initially suggested during the 2012 "Rio+20" summit, to integrate global interests alongside inclusive and green growth. In terms of time, the majority of provinces have demonstrated a consistent upward trend in the total level of *Ingreen*. In terms of space, *Ingreen* has undergone a dynamic evolution process, with obvious spatial autocorrelation in overall space and obvious spatial agglomeration characteristics in local space (Zhou, 2022). Therefore, *Ingreen* is an important indicator for depicting regional economic and environmentally sustainable development, and related research mainly includes two aspects of inclusive growth and green growth.

(1) Inclusive growth level. Social policies that focus on people's livelihood and promote inclusive growth aim to promote comprehensive social development and human wellbeing through integrated investment in human, natural, and social capital, and achieve sustainable and inclusive economic growth. At the micro level, rural infrastructure serves to reduce intra-rural economic inequality and raise the income level of rural populations (Qin et al., 2021). At the macro level, some scholars' studies show that the increasing popularity of inclusive digital finance may contribute to lowering the income gap between rural and urban areas while encouraging economic growth at the same time, thus showing its unique inclusive growth effect (Suhrab et al., 2024) can help to realize balanced distribution of resources, promote social equity and justice.

(2) Green growth level. A vital instrument for creating a society that is resource-efficient and environmentally benign is the green economy, and an innovation to quicken the shift in the manner of economic growth. At the urban level, many scholars combine green growth with economic benefits and investigate how green economic growth affects pollution and carbon reduction, utilizing the mediating effect test approach. Research has found that supporting environmental legislation, energy saving, emission reduction, and urban low-carbon governance may promote green economic growth, encourage green innovation, and enforce laws and technology related to energy conservation and pollution reduction (Dolge and Blumberga, 2021; Belgacem et al., 2023). Green *Inno* also serves a vital mediating function between the low-carbon urban transformation and the digital economy (Zhang and Zhong, 2023). At the industrial scale, industrial activity has a major impact on the national economy, and environmental pollution issues are especially severe and prevalent in industrial production operations. The application of green technologies in the industry has a major influence on encouraging green economic growth, which is especially noticeable in regional variations, with the industrial green growth index becoming substantially greater in the eastern area as opposed to the middle and western areas, showing its leading position in green transformation (Xiong et al., 2023). In the manufacturing sector, through a variety of channels, manufacturing companies' digital transformation has successfully boosted their green innovation initiatives, such as improving operational efficiency, optimizing product design, and strengthening supply chain management, while the development of green technologies having the capacity to innovate is essential for promoting the intelligent manufacturing sector's sustainable growth (Su et al., 2024).

In conclusion, the findings of academic research provide references for this work, nevertheless, the following advancements in the study of *Digagg* and *Ingreen*: First, from a research standpoint, the most recent scholarly studies on the effects of *Digagg* on *Ingreen* is mostly carried out from the single viewpoint of green growth or inclusive growth, and there is no systematic discussion on its impact on *Ingreen*. Second, from the perspective of the construction of an index system, the connotation of *Ingreen*, as the selection criterion of the index, lacks a clear extension and has strong subjective arbitrariness, or there are problems such as a single type of indicator, ignoring the actual meaning of indicator, and difficulties in the actual operation of the index system. Third, from the perspective of research direction, one of the few studies currently available on the relationship between green growth and industrial agglomeration, no scholars have fully revealed the internal transmission mechanism of *Digagg* to promote *Ingreen* by promoting *Inno* and optimizing the *Resource* under the integration framework of resource allocation theory and endogenous economic growth hypothesis. Therefore, the intricate nonlinear connection between *Digagg* and *Ingreen* needs to be discussed.

3 Theoretical analysis and research hypothesis

3.1 Direct conduction mechanism and research hypothesis

China's economy has surpassed forecasts in the digital economy wave and is now a significant contributor to the expansion of the world economy. When economic development's environmentally friendly prerequisites are predetermined, the inexpensive, extensive economic growth mode will be unsustainable. The state has implemented a digital economy policy to encourage the growth of digital business models, industries, and forms, promote green *Inno*, improve resource utilization, reduce energy consumption, and create green jobs, to facilitate the harmonious coexistence of the three. Therefore, building *Digagg* can play a positive role in promoting *Ingreen* at three levels: promoting economic growth, advocating environmental protection concepts, and maintaining social equity.

First, the digital industry, with its powerful radiation and driving role, has emerged as a fresh catalyst for the swift expansion of the local economy. With the support of government initiatives, on the one hand, *Digagg*'s explosive growth has improved digital infrastructure and increased the number of Internet users. Meanwhile, the deep integration of regional traditional industries with emerging technologies such as cloud computing and artificial intelligence has given rise to data as a critical element. This transformation has fundamentally reshaped production models, lifestyles, and economic development paradigms, facilitating a transition towards green and low-carbon growth (Han et al., 2024). As a result, there has been an ongoing decrease in production costs and the continuous stimulation of private sector vitality, including new market entities and enterprises (Alshammry and Muneer, 2023), thereby generating economies of scale and catalyzing a rapid leap within the economy. Conversely, *Digagg* encourages the fast growth of the digital economy, which has the potential to alter how businesses produce, boost their innovation efficiency, quickly meet the market's individualized demand with the aid of information technology, drastically lower their operating and production costs, and promote the expansion of production scale of enterprises, thus generating economies of scale (Cui et al., 2023) and promoting efficient economic expansion.

Second, while pursuing economic benefits, *Digagg* also promotes ecological balance and sustainable growth. From a manufacturing standpoint, the digital sector is a new and ecologically beneficial sector that can encourage the sharing of resources, including sewage equipment, green technology, and low-carbon transformation talents among enterprises, and directly reduce energy consumption. At the same time, new technologies can be combined with traditional industries, lower the cost of businesses' green transformations, and more effectively encourage energy efficiency, emission reduction, traditional industry transformation, and modernization in the area. From the perspective of life, the public is effectively guided by the digital industry to adopt low-carbon practices and engage in social environmental conservation initiatives through the usage of network platforms. Additionally, the utilization of emerging digital technologies like online medical care and telecommuting has promoted the formation of residents' green consumption habits, thereby reducing pollution emissions and energy use.

Third, *Digagg* has a significant impact on encouraging social inclusion and results sharing. It can effectively narrow the regional development gap and become a new way to maintain social equity and sharing in cities. (1) The level of social inclusion and outcome sharing. By optimizing resource allocation and enhancing information sharing, the widespread adoption of digital technology facilitates interaction between enterprises and stakeholders, thereby significantly promoting green product innovation and process innovation (Yin and Zhao, 2024), thus promoting enterprises' green innovation and facilitating the acquisition, analysis, and utilization of data resources. Therefore, the profound incorporation of traditional enterprises and digital technologies significantly improves the information acquisition ability of enterprises and effectively breaks the "data barriers" and "information islands" problems of SMEs (Li et al., 2023b). Compared with traditional industries, the development of *Digagg* significantly enhances the communication and cooperation within and across industries, gradually achieving the co-construction and sharing of information and technology among industries, which supports industry development and integration as well as the general raising of the standard. (2) Regional development and social equity. Massive data sets, cloud computing, and other technologies are developing at a rapid pace in the *Digagg* region, and as a result, the digital economy is progressively permeating every aspect of advancement in society and the economy, gradually strengthening the radiating leading role of developed regions, guiding the flow of digital technologies to the whole country, and gradually eliminating the "digital divide". In the long run, one of the most important factors in closing the regional divide is the growth of the digital economy. Furthermore, the digital economy helps to achieve regional justice and equity by fostering collaboration, sharing, and exchanges between urban and rural areas through a variety of cloud services.

Following the aforementioned analysis, this paper proposes research hypothesis 1: *Digagg* can directly advertise *Ingreen*.

3.2 Indirect transmission mechanism and research hypothesis

Regional inclusive and green growth is an essential component of contemporary social and economic development. Its balanced development, which considers social, economic, and environmental factors, is its defining characteristic. The resource-based allocation theory aims to realize the transfer of resources from low-efficiency fields to high-efficiency fields through market mechanisms or policy guidance to encourage the optimization of economic efficiency in the face of scarce resources. Optimizing *Resource* helps to correct the economic and ecological challenges, such as efficiency loss, cost rise, and environmental deterioration caused by resource misallocation within a region.

Keeping a finger on the pulse of *Inno* is the key to promoting social progress and achieving national prosperity. In the theory of endogenous economic growth, *Inno* is driven by internal factors in the economic system, such as R&D investment and innovation activities. In the digital intelligence era, the phenomenon of

Digagg drives the speed and scale of data accumulation to an unprecedented height, the continuous enhancement of computing power and technology for data processing, as well as the comprehensive advancement of data-intensive knowledge mining, which provides a powerful enablement for technological progress and innovation.

In light of the aforementioned research, this paper focuses on how *Resource* and *Inno* mediate *Digagg*'s influence on the *Ingreen* path.

3.2.1 Analysis of the mediating role of *Resource* in the influence of *Digagg* on the path of *Ingreen*

The development of *Digagg* can provide a broader platform and more abundant opportunities for *Resource* within the region, and enable resources to flow reasonably to areas of high efficiency and high growth, thus contributing positive force to *Ingreen*. *Digagg* can improve the *Resource* both at the global and micro levels, which facilitates the achievement of *Ingreen* in the region. On the one hand, from the macro level, *Digagg* can break through regional restrictions to a certain extent, help increase market transparency, alleviate information asymmetry, reduce retrieval, replication, transmission, tracking and verification expenses (Goldfarb and Tucker, 2019), and enable the market to better play the function of effective *Resource*, thereby effectively incentivizing regional, green, and inclusive growth. On the other hand, from the micro level, the digital agglomeration zone's strong integration of several industries is conducive to industrial restructuring. Further, by adjusting the supply of resources in real-time, enterprises can increase the intelligence, precision, and efficiency of the entire industry's link from research and development to production and sales, and encourage the transfer of resources from high-pollution and high-energy-consuming industries to low-pollution industries. This will improve *Resource*, realize the green industrial structure, and help the industry reach the goal of *Ingreen* at a more advanced stage.

3.2.2 Analysis of the mediating role of *Inno* in the influence of *Digagg* on the path of *Ingreen*

Innovation alters the economic architecture through a "creative destruction process". Innovation will encourage the transition of economic development from quantitative to qualitative transformation, and *Inno* is the key core element of innovation. The upgrading, iteration, and integration of digital technologies propel the digital industry's rapid expansion and quicken the digital transformation of the economy and society, and bring new opportunities for *Inno* for enterprises. Specifically, new infrastructure is contributing to the growth of the information technology sector and the digital transformation of established businesses by facilitating the ongoing invention of emerging technologies, including 5G, AI, and the Internet of Things. The *Digagg* can improve the matching efficiency between *Inno* and market demand, help the innovation achievements to complete the transfer and transformation and value realization, and fully reduce the market risk of innovation activities. Further, the realization of *Inno* can help enterprises improve energy technology, eliminate the backward production capacity with high energy dependence, fully increase business energy efficiency, and encourage the green transformation of industry (Wu and Xu, 2023). Therefore, through continuous *Inno*, regions can create producing techniques that are more ecologically friendly, increase the effectiveness of resource usage, and give all groups equal opportunity for development, which directly improves the efficiency of *Ingreen*.

Therefore, this paper puts forward research hypothesis 2: *Resource*, and *Inno* all serve as mediators in the impact of *Digagg* on *Ingreen*.

3.3 Nonlinear transmission mechanism and research hypothesis

Considering China's notable regional heterogeneity and the Metcalfe rule, *Digagg* may have a nonlinear impact on *Ingreen*.

3.3.1 Threshold effect analysis of *Digagg*

When *Digagg* reaches a certain level, the economic vitality is significantly enhanced, the social structure is more optimized, and the environmental quality is also improved due to the green application of technology, which not only promotes industrial upgrading and economic growth but also provides strong support for social inclusiveness and environmental sustainability. However, the economy and society may suffer from an overabundance of *Digagg*. Excessive agglomeration often results in excessive rivalry for resources at the level of regional economic development, which can lead to uneven distribution, making it difficult for some SMEs to obtain necessary resource support, thus being unable to participate throughout the green growing process, affecting inclusiveness effectively. At the environmental level, due to the consumption and pollution of natural and social resources by a large number of enterprises, regional environmental pressure is intensified. At the social level, *Digagg* tends to attract highly skilled labor, while those with low skills or a lack of relevant training may be excluded, resulting in social exclusion and neglect of more vulnerable groups. As a result, excessive concentration of digital industries can significantly undermine the drive for *Ingreen*.

3.3.2 Threshold effect analysis of Resource

When *Digagg* with specialized specialization in a certain sector can overcome the space-time barrier may continuously improve *Resource* in the initial stage, making the matching of various resource elements more efficient (Zhang, 2021), which is conducive to the efficient aggregation and allocation of innovative resources, and allowing for the agglomeration's scale, resource matching, and technological spillover effects. It empowers regions to make attempts to promote inclusive green development. However, the deepening of agglomeration may harm *Ingreen* due to resource bottlenecks, fierce competition, and other reasons. Especially in urban areas, superior infrastructure conditions lead to excessive concentration of economic activities (Mekaa et al., 2024), which exceeds reasonable limits, leading to bottlenecks in resource flow and distribution, intensifying congestion and competition within cities, and intensifying social stratification and environmental pressure. As a result, inter-regional and inter-enterprise communication efficiency is low, information sharing and technical cooperation are difficult to achieve, and innovation and green technology dissemination are hindered. *Resource* is difficult to

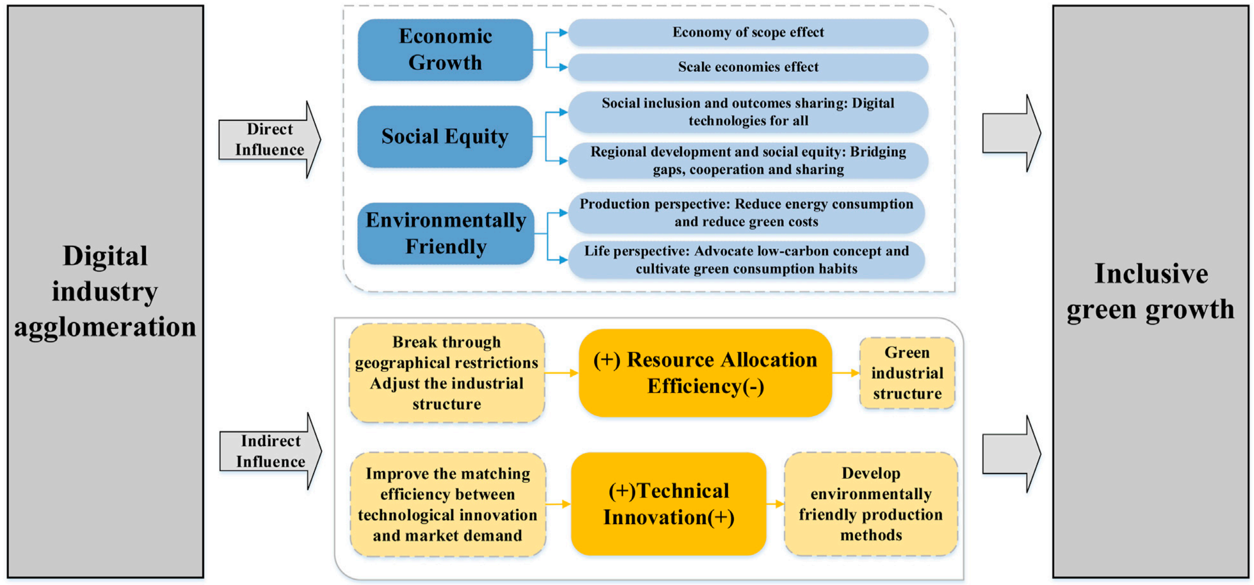

FIGURE 1
The theoretical framework diagram.

effectively improve. Through the above analysis, the positive impact of *Resource* on *Digagg* and *Ingreen* is obvious. However, it is necessary to be vigilant against the weakening effect of excessive agglomeration on *Resource* and seek a balance between the two.

3.3.3 Threshold effect analysis of Inno

One of China's key development priorities is to capitalize on the nation's digital industry's expansion and assist the sector in taking advantage of the opportunities brought forth by digital transformation and modernization. In the course of developing the digital industry, *Inno* takes the lead. When *Digagg* occurs, it greatly promotes the agglomeration of high-quality information-based talents and depends on talent movement to improve knowledge transfer between other industries and the digital sector (Li et al., 2024b), which makes it easier for enterprises in the region to obtain relevant digital technologies, and promote *Inno*. Furthermore, the development of efficient and environmentally friendly technological solutions enhances resource efficiency while simultaneously fostering general social and economic development, becoming a core driving force for *Ingreen*. When the digital industry is over-clustered, corporate *Inno* benefits from leading companies taking advantage of new technologies to reduce costs (Goldfarb and Tucker, 2019), this helps other enterprises with less digital technology development to successfully transform and upgrade while maintaining market competitiveness (Yuan et al., 2023), thus creating a level playing field and stimulating *Inno*. In the meantime, enhancing corporate innovation capacity and encouraging the development and use of green technologies will greatly increase production efficiency and product cleanliness, thereby fostering low-carbon economic growth (Shao et al., 2021), thus boosting *Digagg*'s contribution to *Ingreen*'s promotion.

To sum up, this paper puts forward hypothesis 3: *Digagg* plays a positive non-linear impact on *Ingreen*, and this positive impact is more significant when *Resource* is moderate and *Inno* degree is higher.

The paper's theoretical framework is depicted in Figure 1.

4 Model building and variables measure

4.1 Model construction

The benchmark regression model, intermediary effect model, and threshold regression model are utilized to investigate the direct, indirect, and non-linear effects of *Digagg* on *Ingreen* in order to confirm the three theories proposed in the present research. In this paper, *Digagg* is included in the analysis of *Ingreen*, the establishment of a fixed effect model has the advantage that by introducing individual dummy variables or intra-group estimates, the impact of individual traits that remain constant over time on the outcomes can be possible to successfully eradicate (Zhang et al., 2024), thereby reducing the bias caused by omitted variables. It can distinguish between the time-fixed effect and the individual fixed effect, preventing bias brought on by the correlation between explanatory variables and individual effects, thereby the causal relationship between variables can be more precisely identified. Consequently, the model that follows is formed by Equation 1:

$$Ingreen_{it} = \alpha_0 + \alpha_1 Digagg_{it} + \alpha_n X_{it} + \lambda_i + \varepsilon_{it} \quad (1)$$

Among them, i denotes the province, t denotes the year, $Ingreen_{it}$ denotes the regional i's *Ingreen* of the province in the year t, $Digagg_{it}$ is this paper's central variable, indicating the degree of *Digagg* in province i during year t, and X_{it} denotes the control variable in this model, which includes the degree of marketization (hereinafter referred to as *Market*), the degree of exposure to the external environment (hereinafter referred to as *Open*), the level of global competition (hereinafter referred to as *Intercom*), and population density (hereinafter referred to as *Human*). In addition, considering that there are still some unobserved factors in reality that will also affect *Ingreen*, this paper includes the unobserved individual fixed effect λ_i and random error term ε_{it}, α_1, α_n are the coefficients of each variable, and α_0 represents the intercept term.

Further, this paper introduces two types of intermediary variables, *Inno* and *Resource*, and the mediation effect model is employed in this study to examine the internal action path and mechanism of *Digagg* and *Ingreen*. On the one hand, this model significantly reduces the error rates of the first and second types by combining procedures such as the sequential test method and the Sobel test. Both partial and total mediating effects can be verified through it. On the other hand, various effect sizes measurement methods, such as partial standardization, full standardization, proportion, and ratio, are provided. These methods have advantages such as unbiasedness, high efficiency, and confidence interval stability, enhancing the explanatory power of the results. Thus, the model is established as Equations 2, 3:

$$Mediation_{it} = \beta_0 + \beta_1 Digagg_{it} + \beta_n X_{it} + \lambda_i + \varepsilon_{it} \tag{2}$$

$$Ingreen_{it} = \omega_0 + w_1 Digagg_{it} + w_2 Mediation_{it} + w_n X_{it} + \lambda_i + \varepsilon_{it} \tag{3}$$

Furthermore, the threshold regression approach is employed in this research to build a threshold panel model with *Digagg* and *Inno* as the threshold variables. The threshold effect between *Digagg* and *Ingreen* is tested. The threshold effect model, as a nonlinear analysis method, has the core advantage of being able to identify the nonlinear relationships among variables. Especially when a certain explanatory variable reaches a specific critical value, its influence on the explained variable changes significantly (Zhao et al., 2020). On the one hand, by figuring out the important thresholds, this model clarifies the critical conditions for the effects of variables, providing a basis for scientifically delimiting the boundaries of policy intervention. On the other hand, it overcomes the drawbacks of the conventional linear model and provides a more precise fit to the data, improves the predictive ability (Fu and Peng, 2020), and effectively coordinates multiple objectives. Consequently, the threshold regression model developed in this work resembles Equations 4, 5:

$$Ingreen_{it} = \mu_i + \theta_1 Digagg_{it} \cdot I\left(threshold_{it} \le \gamma\right) + \theta_2 Digagg_{it} \cdot I\left(threshold_{it} > \gamma\right) + \theta_n X_{it} + \lambda_i + \varepsilon_{it} \tag{4}$$

$$Ingreen_{it} = \mu_i + \theta_3 Digagg_{it} \cdot I\left(threshold_{it} \le \gamma_1\right) + \theta_4 Digagg_{it} \cdot I\left(\gamma_1 < threshold_{it} \le \gamma_2\right) + \theta_5 Digagg_{it} \cdot I\left(threshold_{it} > \gamma_2\right) + \theta_m X_{it} + \lambda_i + \varepsilon_{it} \tag{5}$$

Among them, $threshold_{it}$ is the threshold variables set in this paper, *Digagg*, *Resource*, *Inno*, ω and θ are the corresponding coefficient vectors, γ is the threshold value, $I(\cdot)$ is the directive function, when the associated conditions are met, the value is one; otherwise, it is 0. As previously mentioned, control variables are is the same.

4.2 Measurement and description variables

4.2.1 Explained variable

Considering that the measurement of *Ingreen* is a complex and comprehensive issue involving many aspects such as economy, society, ecology, resources, and environment (Fan et al., 2023), domestic and foreign academic circles have yet to reach a consensus on the definition and expansion of *Ingreen*. Drawing from an abundance of scholarly accomplishments, this study outlines the expansion of *Ingreen* as the content of three systems: economy, society, and nature. Its connotation is defined as a sustainable development mode that pursues economic growth, social equity, achievement sharing, preservation of resources, and a healthy natural setting. Based on this, the indicators' scientific, dynamic, and logical nature has been thoroughly examined, and a detailed *Ingreen* indicator system has been established, focusing on the internal linkages and interactions among the indicators.

As for the indicator system, as indicated in Table 1, this article primarily discusses *Ingreen* from four perspectives: economic development, social opportunity equity, ecological environmental conservation, and green production and consumption. In particular, two conflicting but complementary components of economic progress are typically shown: the increase in output and the rise in income. It has the highest weight in the index of *Ingreen*, and its growth rate directly affects the overall level, providing a material basis for other dimensions. However, its growth model must be constrained by ecological boundaries and social equity. Equity of social opportunity is characterized by the balanced distribution of five key areas - employment opportunities, educational resources, medical services, social security system, and infrastructure construction, which together form the basis of social equity. It mainly ensures the inclusiveness of economic growth by reducing the gap between the rich and the poor (Huang, 2021), enhancing human capital and welfare inclusiveness (Liu et al., 2023b). The sustainability of the two production and consumption relationships is the main concern when it comes to green production and consumption. The production link emphasizes the reduction of resource consumption and pollution emissions, while the consumption link advocates for the public to choose environmentally friendly products and services, form a green lifestyle, and jointly encourage the shift in society toward green economic growth. Green production and consumption, as a link between the economy and the ecology, can guide the production end to upgrade towards cleanliness, forming a virtuous cycle of "demand side pulling supply side" (Lei et al., 2025). As for ecological and environmental protection, the green economy emphasizes keeping the ecological footprint within the "boundaries of the earth", providing natural capital for economic and social activities. Its evaluation criteria mainly focuses on two aspects: First, the effect of ecological and environmental governance. The second method is to gauge a region's level of ecologicalization, which includes ecological services, biodiversity preservation, and ecosystem health. Once damaged, it will restrict the long-term growth potential. As can be seen from the above, there exists multi-dimensional synergy and dynamic balance among these four dimensions. Economic development is the material basis and provides support for other dimensions. Social opportunity equity guarantees growth, and inclusiveness, and

TABLE 1 *Ingreen* indicator system.

First-level indicators	Secondary indicators	Tertiary indicators	Indicators
Inclusive green growth	Economic development	Economic output	Gross regional product
			Gross regional product *per capita*
			Value-added of the tertiary industry as a percentage of GDP (%)
		Income level	Per capita disposable income of urban residents
			Per capita disposable income of rural residents
	Social opportunity equity	Employment opportunity equity	Employment rate in secondary and tertiary industries (%)
			Urban registered unemployment rate (%)
		Equity in educational opportunity	Intensity of educational expenditure (%)
			Educational resources per 10,000 people
		Equity in health access	Number of health technicians per 10,000 population
			Number of hospitals per 10,000 population
			Number of beds in medical and health institutions per 10,000 population
		Equality of social security opportunities	Number of urban workers enrolled in basic medical insurance at the end of the year
			Number of urban workers participating in old-age insurance
		Fair infrastructure conditions	Length of line network per 10,000 people
			Public transport vehicles per 10,000 people (standard station)
			Urban road area *per capita*
			Urban gas penetration rate (%)
	Ecological and environmental protection	Ecological and environmental governance	Harmless treatment rate of domestic waste (%)
			Comprehensive utilization rate of general industrial solid waste (%)
		Ecological and environmental endowment	Water resources *per capita*
			Park green space *per capita*
			Forest coverage (%)
	Green production and consumption	Green production	Carbon dioxide emissions per unit of output value
			Sulfur dioxide emissions per unit of output value
			Industrial wastewater discharge per unit of output value
		Green consumption	CO_2 emissions *per capita*
			Sulfur dioxide emissions *per capita*
			Electricity consumption *per capita*
			Daily domestic water consumption *per capita*

promotes the rational allocation of resources. Green production and consumption connect the economy with the environment and encourage sustainable growth. Ecological and environmental protection establishes boundaries to guarantee sustainable growth. Establishing a three-in-one policy system of "scale control - fair distribution - efficiency improvement" can enhance the coordination among all dimensions and is conducive to jointly promoting the realization of the goal of *Ingreen*.

As for the measurement method, the evaluation value of regional savable development potential is determined using a real coding accelerated genetic algorithm as the basis for the projection pursuit model. As a comprehensive evaluation model, the projection pursuit model has the benefits of excellent adaptability to nonlinearity and complexity, good flexibility and resilience, and the capacity to overcome the influence of the "dimensionality bane". It is utilized to manage complex multi-index and objectivity-emphasized comprehensive evaluation systems. During the optimization process, the accelerated genetic algorithm based on real number coding can more freely search the solution space and quickly approach the ideal answer or an estimated optimal solution, which can greatly increase the problem's accuracy and efficiency. As a result, the outcomes have the advantages of science and robustness. By developing a judgment matrix and hierarchical structure, the Analytic Hierarchy Process (AHP) can break down complex problems into multi-level indications in comparison to this measuring technique (Guo et al., 2008), and can handle problems of fuzzy or lack of data in combination with expert experience. However, by default, the indicators of this method have a linear relationship, making it difficult to handle nonlinear or high-dimensional data and prone to result in deviations (Pant et al., 2022). The foundation of data envelopment analysis (DEA) is the assessment of input-output data's comparative efficiency. It is highly objective and can simultaneously analyze the complex relationships among multiple indicators (Gao et al., 2024). However, DEA has two drawbacks. On the one hand, DEA only focuses on the forefront of efficiency and ignores the variations in indicators and blames efficiency problems for all departures from the "best practice frontier" (Liu et al., 2019). On the other hand, DEA needs an extensive number of samples to be supported because it is susceptible to anomalies; otherwise, it will lead to poor stability of the results (Batiz-Zuk and Lara-Sanchez, 2021). Therefore, by using the accelerated genetic algorithm based on real number coding for the solution, the solution space can be more freely searched throughout the optimizing process, and it can rapidly converge to the ideal or nearly ideal solution. This can significantly improve the efficiency and accuracy of solving the problem. Thus, robustness and scientificity are benefits of the results produced.

4.2.2 Core explanatory variable

Digagg. Compared with other industrial agglomeration measurement methods, the location entropy index has the advantages of convenient data collection and simple calculation, which can eliminate the influence of external factors such as regional-scale differences, and is frequently employed to gauge a region's level of industrial agglomeration (Huang et al., 2020). It aids in recognizing and evaluating the phenomena of industrial agglomeration and developing strategies to promote industrial upgrading and regional economic expansion. The information transportation, software, and information technology services sectors are chosen in this article to represent the digital industry based on the definition of the National Bureau of Statistics and data availability. The following Equation 6 is the calculation formula:

$$Digagg = \frac{EMD_{it}/EM_{it}}{\sum EMD_{it}/\sum EM_{it}} \tag{6}$$

where, EMD_{it} is the number of digital industry employees in period t of region i, and EM_{it} is the number of urban employment in the region i, t period. The number of workers in the software, information technology services, and information transportation sectors combined represents the workforce in the digital sector. *Digagg* indicates a higher degree of *Digagg* in the region.

4.2.3 Mediation variables and threshold variables

Resource, and *Inno* are chosen as the intermediary variables of empirical research in this paper. Furthermore, *Digagg* is introduced and the three factors are treated as threshold variables. Among them, the representation of *Digagg* is mentioned in the explanatory variables.

4.2.3.1 Resource

The allocation state where the unrestrained movement of elements maximizes the societal output under the market mechanism is known as the effective allocation of resources, and the misallocation of resources means the deviation from this state. Citing the pertinent research of relevant scholars, the C-D production function is constructed using the Solow residual approach, which takes the logarithm of constant returns to scale: $ln(\frac{Y_{it}}{H_{it}}) = lnA + \beta_{Ki} ln(\frac{K_{it}}{H_{it}}) + \mu_i + \delta_t + \varepsilon_{it}$. Following the custom of Chen and Hu (2011), as well as the relative distortion coefficient of labor and capital prices, the relative distortion coefficient of labor and capital prices is computed. The specific values are: $\hat{\gamma}_{Kit} = \frac{K_{it}}{K_t}/\frac{s_{it}\beta_{Ki}}{\beta_{Kt}}$, $\hat{\gamma}_{Hit} = \frac{H_{it}}{H_t}/\frac{s_{it}\beta_{Hi}}{\beta_{Ht}}$, where, $\beta_{Kt} = \sum_{i=1}^{n} s_{it}\beta_{Ki}$, $\beta_{Ht} = \sum_{i=1}^{n} s_{it}\beta_{Hi}$ are the output-weighted contribution value of capital and contribution value of labor respectively. Finally, both the labor mismatch index and the capital mismatch index are computed according to the $\hat{\gamma}_{Kit}$ and $\hat{\gamma}_{Hit}$ expression. The *Resource* is higher when the resource misallocation index is lower. on the other hand, *Resource* is higher.

4.2.3.2 Inno

In the context of the digital economy, *Inno* can save energy and resources, reduce pollution, and develop a healthy ecological environment by using better products and production methods, which is conducive to *Ingreen*. This paper draws on the method of Zhao et al. (2024) to measure technology accumulation by the quantity of patents awarded, whereby the more patents awarded, the more capable *Inno*.

4.2.4 Control variables

The advertising of *Ingreen* is influenced by many other factors besides *Digagg*. To ensure the validity of the empirical findings, the current study incorporates a few control variables, including *Market*, *Open*, *Intercom*, and *Human*. (1) *Market*. In regions with a high degree of *Market*, financial support is more accessible, which can effectively promote the development of green start-ups and significantly increase their survival rate by 18%–25% (Li and Liu, 2022). Meanwhile, a high degree of *Market* means that the proportion of capital entering the environmental protection industry has increased rapidly, greatly promoting the diffusion of green *Inno* (Liu et al., 2023a). Therefore, the degree of *Market* has an important impact on *Ingreen*. This paper adopts the measurement method of Bai et al. (2022) to represent the ratio of budget expenditure to GDP. (2) *Open*. *Open*, becoming the main motivation for *Ingreen*, can promote the deep integration of economic growth, ecological protection, and social equity through paths such as the construction of international trade networks, cross-border transfer of low-carbon technologies and

TABLE 2 Descriptive statistics of each variable.

Variables	*Ingreen*	*Digagg*	*Market*	*Open*	*Intercom*	*Human*
Obs	360	360	360	360	360	360
Mean	2.334	1.284	0.248	0.259	5.572	7.922
SD	0.480	2.448	0.102	0.270	0.978	0.389
Min	1.109	0.206	0.107	0.008	2.396	6.933
Median	2.327	0.648	0.225	0.144	5.445	7.956
Max	3.645	17.171	0.643	1.441	7.733	8.620

international coordination of environmental regulations (Zhang and Zhuang, 2023), thereby playing a role in *Ingreen*. According to the neoclassical growth theory and endogenous growth theory, an open economy promotes growth through capital flow and technology diffusion, and trade dependence can measure the contribution of openness to economic growth, so the percentage of each province's GDP that goes toward total foreign trade is employed in this study to illustrate *Open* (Zhang et al., 2022). (3) *Intercom*. Against the backdrop of the accelerated reconstruction of the global competition paradigm, *Ingreen* has evolved into a strategic fulcrum for reshaping a country's core competitiveness. Through the three-dimensional synergy of institutions, technologies, and markets, the engine of economic expansion has changed from the conventional "scale expansion" to the "quality leap". While achieving GDP growth, the Gini coefficient and carbon emission intensity are systematically reduced (Ma et al., 2022; Zeng et al., 2024), which has an impact on *Ingreen*. The ratio of total imports and exports to GDP was employed to measure this particular commodity (Li et al., 2023). (4) *Human*. According to the spatial distribution theory, *Human* is the core index to describe the characteristics of population distribution in geographical space, reflecting the agglomeration or dispersion pattern of population. Existing research shows that *Human* measures the degree of agglomeration of economic activities. Digital industries should be guided to cluster in areas with moderate *Human* to balance the scale effect and resource carrying capacity (Liu et al., 2024), which is consistent with the theory of population distribution. Areas with high *Human* usually have more complete digital infrastructure and more concentrated productive service industries (Zhong et al., 2020), which enables *Digagg* to consume resources more efficiently and use less energy by taking advantage of economies of scale. Therefore, in this paper, the measuring index of *Human* is determined to be the quantity of long-term inhabitants per square kilometer.

4.3 Data source

In this paper, 30 provinces in China from 2012 to 2023 are selected as research samples, and the data from Tibet, Hong Kong, Macao, and Taiwan in China are deleted due to obvious deficiencies. The National Bureau of Statistics also provides information on *Digagg*, *Resource*, *Inno*, and control factors. Additionally, to get rid of the issues caused by price fluctuations and control the estimation bias, the relevant variables involved in this paper are logarithmic. The descriptive statistical data for each variable are shown in Table 2.

5 Empirical results and discussion

5.1 Analysis of the characteristics of *Ingreen*

Figure 2 shows the mean distribution of *Ingreen* in 30 provinces. The darker the color, the higher the amount of *Ingreen* (colorless areas denote missing data and are not samples of this study). Overall, *Ingreen* shows a gradient distribution of "East - Middle - West". The eastern region includes coastal cities such as Shanghai and Zhejiang. The darker color indicates a higher level of *Ingreen*. These regions, relying on their economic heritage, technological strength, and talent aggregation advantages, are taking the lead in the green transformation. Cities in central regions such as Henan and Hubei have relatively moderate levels of *Ingreen*. Although these regions have made breakthroughs in ecological economy and innovative applications, they still have a gap compared with the eastern regions due to the constraints of location conditions, industrial structure and the allocation of *Inno* and scientific resources. Nonetheless, the amount of *Ingreen* is very low in the western areas, including Xinjiang and Qinghai. Nevertheless, with the expansion of public assistance programs for the central and western regions and the advancement of the regional coordination strategy, the benefits of green development for late entrants in the central and western regions will gradually be released, and it is anticipated to close the development gap between regions and produce a leapfrog improvement in the future.

5.2 Benchmark regression analysis

After the DWH test, the presence of endogenous explanatory variables in the model is demonstrated by the statistical significance at the 0.01 level. Therefore, in this paper, the fixed effect model is utilized for comparative analysis, and the model is estimated employing the two-stage least squares method, difference GMM, and the addition of instrumental variables. The telephone penetration rate (hereinafter referred to as *iv*) is chosen in this article as the instrumental variable, which meets the conditions for choosing the variable employed by the instrument.

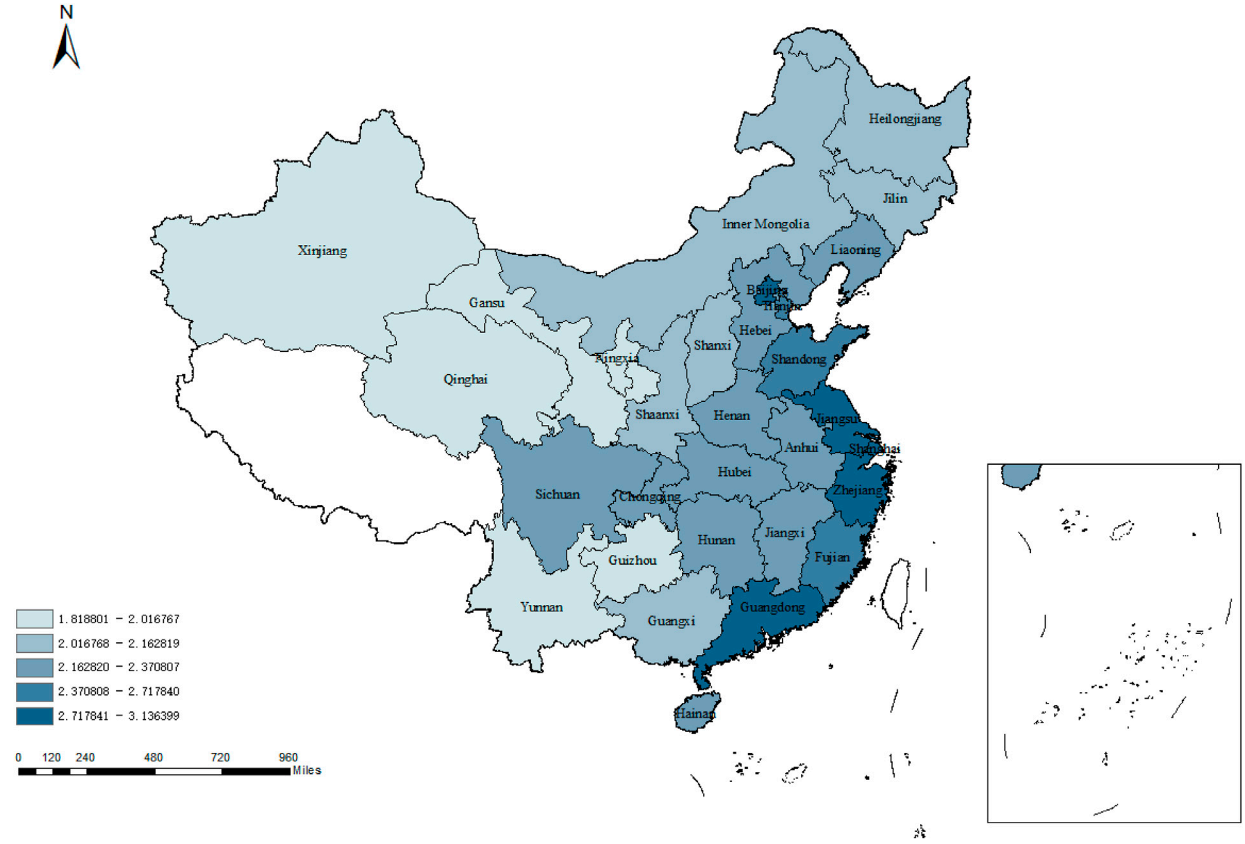

FIGURE 2
Spatial distribution of the mean value of *Ingreen* in each region.

Column (1) in Table 3 shows the estimation results without adding control variables, and Column (2)–(5) show the estimation results with adding control variables one by one. According to Column (5), the overall analysis of the direct effects across the country shows that the influence coefficient of *Digagg* on inclusive green innovation is 0.215 and relatively significant. *Digagg*'s development trend contributes to the promotion of *Ingreen*, and this positive impact shows its beneficial effect to a certain extent, confirming the hypothesis one proposed at the beginning of the study. It provides support for environment-friendly and inclusive growth. In Table 3's Column (7), the Cragg-Donald Wald statistical value is 80.749, which is greater than 16.38, the 10% critical restriction, suggesting that weak instrumental variables are not a problem. Given that the second-order sequence is not in Column (8) and the first-order sequence is correlated, it indicates that the endogeneity of the model has been overcome.

Regarding the control variables, for each unit rise in the degree of *Market*, *Ingreen* will decrease by 0.082 units. According to this article, the explanation could be that the rise in the level of *Market* may intensify competition, leading to the concentration of resources in areas with short-term high benefits. The green industry receives insufficient support due to the large initial investment and slow returns. Meanwhile, market profit-seeking may weaken the impetus for internalizing environmental costs. Some enterprises take advantage of regulatory loopholes to harm fairness and the environment. Moreover, if *Inno* is concentrated in non-green fields or green innovation is insufficient, it may all inhibit *Ingreen*. The influence coefficient of *Open* on *Ingreen* is positive but not significant at the level 1%. Different regions are promoting high-quality market integration with greater intensity, deeper level, and higher level, and fulfilling the demands of China's economic transition from rapid expansion to high-quality development through comprehensive opening-up (Zhong et al., 2022). Consequently, the greater the level of exposure to the external environment, the more conducive to green economic growth. *Intercom* is not conducive to promoting *Ingreen*, with an elasticity coefficient of −0.123. According to this paper, one potential explanation is that leading countries or enterprises may not be willing to share digital or green technologies to maintain international competitiveness, thus forming technical barriers, which is one of the key factors that China urgently needs to overcome technological challenges. When *Human* increases by one unit, *Ingreen* will fall by 0.833 units. The increase in *Human* may intensify resource consumption and environmental pressure, leading to a rise in pollution sources such as traffic exhaust and domestic waste. At the same time, it will increase the difficulty of social management, resulting in a sharp increase in employment pressure and insufficient carrying capacity of energy and resources, thereby inhibiting *Ingreen*.

TABLE 3 Baseline regression results.

Variables	*lngreen*							
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Digagg	0.203***	0.203***	0.202***	0.208***	0.215***		0.294***	0.028***
	(7.63)	(7.58)	(5.99)	(6.01)	(6.72)		(5.32)	(5.90)
Market		0.013	0.010	−0.022	−0.082	−0.172	−1.967***	−1.763***
		(0.02)	(0.02)	(-0.03)	(-0.14)	(-0.44)	(-6.54)	(-13.56)
Open			−0.014	0.129	0.223	−1.066***	−1.365***	−0.542***
			(-0.05)	(0.36)	(0.67)	(-6.38)	(-3.55)	(-9.99)
Intercom				−0.053	−0.123**	−0.061	0.139*	−0.005
				(-0.82)	(-2.03)	(-1.60)	(1.84)	(-0.34)
Human					−0.833***	−0.393***	0.139*	−0.284***
					(-7.74)	(-5.48)	(1.95)	(-5.52)
L1.lngreen								0.784***
								(25.37)
iv						0.019***		
						(23.77)		
DWH						P = 0.000		
Cragg-Donald Wald F							80.749	
AR(1)								P = 0.020
AR(2)								P = 0.129
Hansen test								P = 0.211
cons	2.074***	2.071***	2.076***	2.336***	9.310***	3.715***	0.923	
	(54.36)	(12.22)	(9.86)	(6.13)	(9.63)	(5.56)	(1.36)	
N	360	360	360	360	360	360	360	300

Note: *** indicates significance at the level of 0.01; ** indicates significance at the level of 0.05; * indicates significance at the level of 0.1. The t value is in parentheses. The following tables are the same.

5.3 Analysis of regional heterogeneity impact

This study uses the three main areas of eastern, central, and western of China as samples for regression tests and analyses based on regional heterogeneity. Through empirical tests on sample data at these three different levels, this paper explores and compares the regional heterogeneity impact of *Digagg* on *lngreen*. Table 4 reports the regional heterogeneity estimation results of *Digagg* on *lngreen*.

According to the results, *Digagg*'s effect on *lngreen* of the three main regions is shown to follow the pattern "Western region > Central region > Eastern region". Based on this research, the cause of this pattern is that the eastern region is more likely to reach the inflection point of agglomeration benefits, while the central and western regions still need to strengthen the accumulation of factors. This is consistent with the conclusion proposed by scholars Zhao et al. (2024) that regions with weak digital foundations can achieve greater green innovation improvements from agglomeration. Specifically, the digital economy's growth is tailored to regional circumstances. As digital infrastructure is a crucial support for modern economic activities, its imperfection directly leads to poor information flow both within and outside the region, hindering the cross-temporal and spatial dissemination of important industrial elements, including information and data (Li et al., 2023a). Intending to create a contemporary infrastructure system that is organized, comprehensive, effective, useful, intelligent, green, safe, and dependable, the central and western regions have been encouraging the coordinated building of both new and historic infrastructure in recent years. This has greatly enhanced the marginal output efficiency and strengthened the overall competitiveness and sustainable development capacity of the local economy. In the eastern areas, economic development is relatively mature, with a relatively complete smart industrial system and digital infrastructure, which provides a good foundation for promoting green production methods and economic development with low carbon emissions. Meanwhile, with its abundance of educational resources and excellent scientific and *Inno* capabilities, the eastern area can offer substantial intellectual support for the development and

TABLE 4 Results of regional heterogeneity estimation.

Variables	(1) Eastern region	(2) Central region	(3) Western region
Digagg	0.158***	1.524***	1.999***
	(7.03)	(6.87)	(7.70)
Market	4.298***	1.751	−2.182***
	(7.46)	(0.91)	(-2.75)
Open	−0.755***	3.436	−0.637
	(-2.71)	(1.30)	(-0.66)
Intercom	0.293***	0.296	−0.247***
	(3.08)	(1.47)	(-3.64)
Human	−1.016***	0.072	−0.572***
	(-7.66)	(0.25)	(-4.82)
cons	7.830***	−1.456	7.413***
	(6.41)	(-0.52)	(6.47)
N	156	72	132
R^2	0.637	0.656	0.571

implementation of green technology. In addition, the eastern region can, based on its resource endowment and comparative advantages, effectively absorb advanced technologies, talents, and other resource elements, enhance the regional productivity level, and encourage the coordinated, equitable, and environmentally friendly growth of local enterprises.

5.4 Mechanism analysis

The test results of the intermediary mechanism of *Digagg* affecting *Ingreen* are shown in Table 5. Hypothesis two in this paper is sufficiently supported by the analysis of the influence coefficients and significance levels of the model's key and intermediary variables, which show that *Digagg* somewhat indirectly influences *Ingreen* under the influence of *Resource* and *Inno*. In particular, models (1) and (2) in Table 5 use *Resource* as the intermediary variable to report the model estimation results. The influence of *Digagg* on *Resource* is significantly positive, whereas the influence coefficient is 0.089, and the direct influence coefficient on *Ingreen* is 0.050. However, with the assumption that other elements stay the same, alleviating the degree of resource misallocation can achieve the growth of *Resource*, for every 1 unit change in *Resource*, it will significantly increase *Ingreen* by 0.055 units. In accordance with this research, the explanation could be that the fixing of resource misallocation implies the redistribution of labor, capital, and technology as production inputs from inefficient fields, such as overcapacity industries or highly polluting industries, to efficient fields such as green technologies or renewable energy (Peng et al., 2022). This kind of flow directly enhances the marginal output per unit of resources, forms a growth effect of total factor productivity, and drives a significant improvement in *Resource*. Meanwhile, if the dividends of technological progress are not effectively transformed into the driving force for green innovation, it may widen the development gap among regions and instead weaken the inclusiveness and sustainability of *Ingreen*. Then, model (3) and model (4) in Table 5 carry out gradual regression with *Inno* as the intermediary variable based on baseline regression. Under the influence of *Inno*, the indirect effect (0.013) of *Digagg* on *Ingreen* is consistent in direction with its direct effect (0.032), suggesting that controlling the level of *Inno* can enhance the effect of *Digagg* on *Ingreen*. *Digagg* promotes modernization and industrial change, as well as the quick advancement of clean production technologies. *Ingreen* is facilitated by the synergistic effect of technological spillover and green innovation. This aligns with the theoretical expectations of the "green value realization path" under the framework of the digital economy paradox (Xiang et al., 2022). All in all, *Digagg* has indirect effects in the same role on *Ingreen* in the two paths for regional *Ingreen*, which supports hypothesis two by showing that *Digagg* influences *Ingreen* not only directly through spillover but also through different transmission paths to a certain extent.

5.5 Threshold regression analysis

It is evident from Table 6's threshold effect test that at the 5% significance level, the single threshold of *Resource* is significant, but the double threshold is not. The single threshold values of Digagg and Inno are significant at the 5% level, while the double threshold values are significant at the 10% significance level, suggesting that *Resource* has a substantial single threshold effect and *Digagg* and *Inno* have a notable double threshold effect in the model.

This study examines the panel threshold model setting employing *Digagg*, *Resource*, and *Ingreen* as threshold variables in accordance with the threshold theory. Table 7 displays the specific outcomes. Among the influence mechanisms of *Digagg* to promote

TABLE 5 Mechanism test results.

Variables	(1) *Resource*	(2) *Ingreen*	(3) *Inno*	(4) *Ingreen*
Digagg	0.089***	0.050***	0.042*	0.032***
	(4.84)	(4.75)	(1.68)	(4.86)
Market	0.019	−1.448***	−9.317***	1.480***
	(0.04)	(-5.52)	(-14.46)	(6.99)
Open	0.096	0.357**	1.239**	−0.037
	(0.33)	(2.21)	(3.12)	(-0.35)
Intercom	−0.071	0.035	−0.059	0.057*
	(-0.82)	(0.72)	(-0.50)	(1.85)
Human	0.602***	−0.132**	0.117	−0.202***
	(6.62)	(-2.44)	(0.94)	(-6.18)
Resource		−0.055*		
		(-1.85)		
Inno				0.314***
				(22.70)
cons	−4.070***	3.411***	11.778***	−0.068
	(-4.44)	(6.48)	(9.35)	(-0.19)
Sobel	Z = −1.725		Z = 1.676	
Test	P = 0.085		P = 0.094	
Bootstrap	Z = −2.340		Z = 2.960	
Test 1	P = 0.019		P = 0.003	
N	360		360	
R^2	0.154	0.452	0.616	0.775

TABLE 6 Threshold effect test.

Threshold variables	Threshold	F Value	P Value	Number of BS	10%	5%	1%
Digagg	Single threshold	82.87	0.0133	300	60.6236	67.6832	86.0467
	Double threshold	45.57	0.0700	300	40.8962	47.7577	59.2616
	Triple threshold	41.31	1.0000	300	148.9393	162.0005	182.8476
Resource	Single threshold	71.31	0.0333	300	57.9305	62.9560	85.7285
	Double threshold	13.99	0.1467	300	17.2777	19.7845	32.1560
Inno	Single threshold	97.78	0.0367	300	84.1686	92.7855	110.9231
	Double threshold	45.68	0.0567	300	40.7496	46.8839	61.9166
	Triple threshold	29.96	0.9300	300	114.4982	132.0141	208.5474

Ingreen, there are significant, single threshold effects of *Resource* and double threshold effects of *Digagg* and *Inno*. The double threshold values of *Digagg* are 0.3513 and 0.4529, respectively. And the single threshold values of *Resource* are 0.8394, respectively. 9.2210 and 10.1339 are the double threshold values for *Inno*.

This study employs the least squares likelihood ratio statistic LR, to determine the threshold value in order to more clearly view the estimated outcome of the threshold value and the associated 95% confidence interval. The value at which LR is 0 is known as the threshold estimate. The likelihood ratio function graph is displayed

TABLE 7 Threshold estimates and confidence intervals.

Threshold variables	Threshold	The threshold estimate	95% confidence interval
Digagg	Single threshold	0.3513	[0.3504,0.3522]
	Double threshold	0.4529	[0.4487,0.4538]
Resource	Single threshold	0.8394	[0.7232,0.8506]
Inno	Single threshold	9.2210	[9.1943,9.2460]
	Double threshold	10.1339	[10.1181,10.1680]

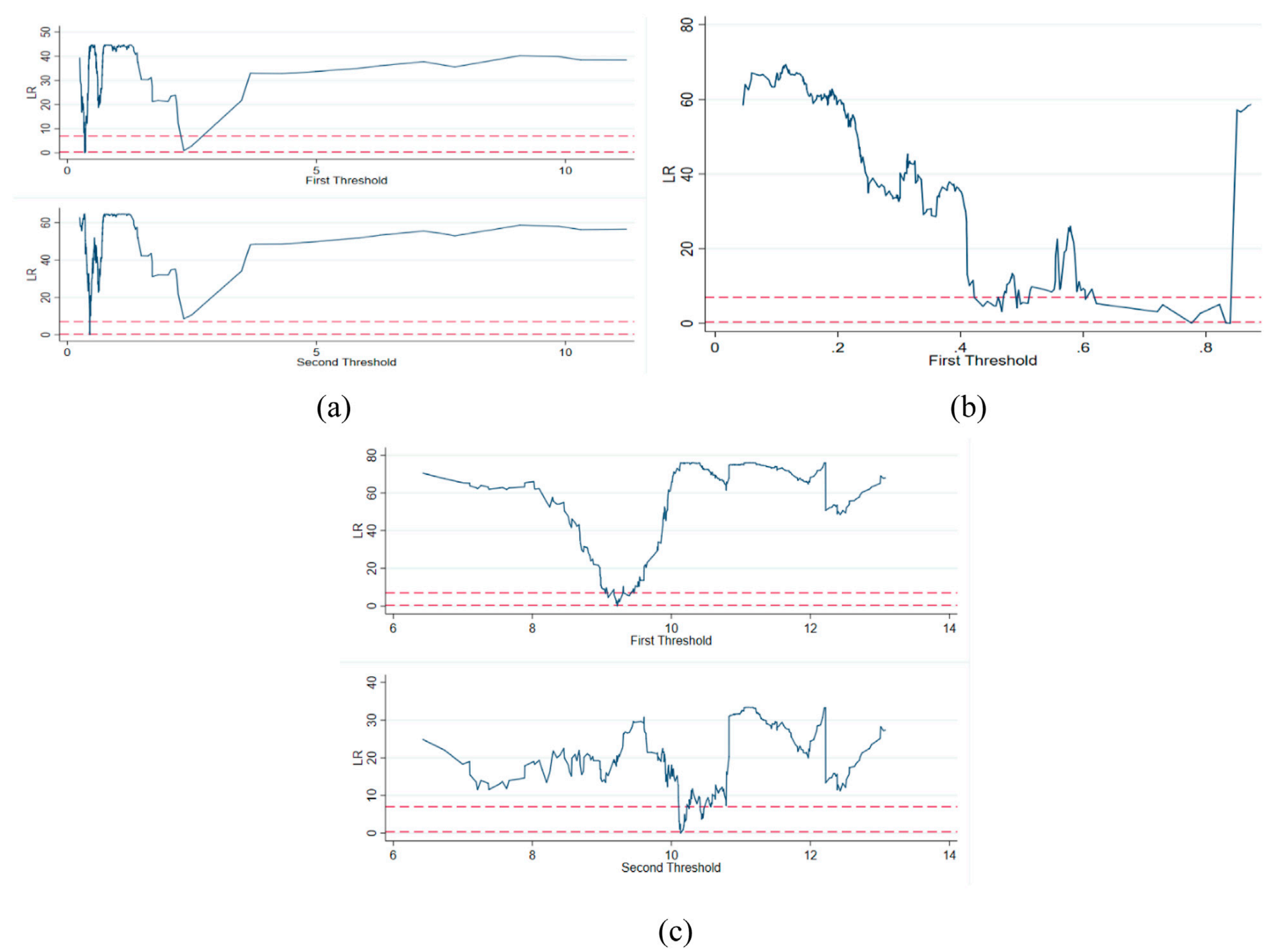

FIGURE 3
Likelihood ratio function of each threshold variable: *Digagg* **(a)**, *Resource* **(b)**, *Inno* **(c)**.

in Figure 3 with *Digagg*, *Resource*, and *Inno* as the threshold values.

Table 8 displays the restricted effects of each threshold variable. (1) *Digagg* is used as the threshold variable in Model (1) in Table 8, which shows the estimated outcomes. When *Digagg* is below the cutoff point of 0.3513, *Digagg* is considerably positive at the 1% threshold, suggesting that when the degree of *Digagg* is low, regional *Digagg* is conducive to promoting *Ingreen* and plays a positive role. When the degree of *Digagg* exceeds the first and second threshold values, *Digagg* is notably negative at the 1% level, suggesting that when the digital sector is overly centralized, *Digagg* is not conducive to the development of *Ingreen*, showing a negative role. This finding indicates that a comparatively low level of *Digagg* is beneficial for its capacity to stimulate economic growth. When the level of *Digagg* exceeds a certain threshold, its driving force will be significantly weakened, which will inhibit *Ingreen*. The research conclusion needs to be examined inside the theoretical framework of industrial agglomeration's "inverted U-shaped". The current *Digagg* has significant beneficial effects on the left side of the inverted U-shaped curve throughout the ascent phase when it is less extensive than the initial threshold value; Conversely, it is in the downward stage on the right side. (2) When *Resource* is the

TABLE 8 Results of threshold regression.

Variables	*Ingreen*		
	(1)	(2)	(3)
Digagg (*Digagg* ≤ 0.3513)	0.179***		
	(6.51)		
Digagg (0.3513 < *Digagg* ≤ 0.4529)	−0.857***		
	(-6.29)		
Digagg (*Digagg* > 0.4529)	−1.957***		
	(-9.33)		
Digagg (*Resource* ≤ 0.8394)		0.874***	
		(10.16)	
Digagg (*Resource* > 0.8394)		0.221***	
		(7.57)	
Digagg (*Inno* ≤ 9.2210)			−1.024***
			(-9.38)
Digagg (9.2210 < *Inno* ≤ 10.1339)			−0.287***
			(-3.82)
Digagg (*Inno* ≥ 10.1339)			0.194***
			(7.23)
cons	7.675***	7.508***	9.819***
	(9.13)	(8.26)	(12.03)
Control variables	Yes	Yes	Yes
N	360	360	360
R^2	0.479	0.406	0.498

threshold variable, model (2) in Table 8 displays the empirical findings. When *Resource* is less than the threshold value (0.8394), the degree of resource misallocation is low, and most resources are allocated to the area that can produce the greatest social welfare or economic value. Therefore, resources can be fully utilized in *Digagg* area, showing a significant positive effect. Given the restriction of a high resource mismatch, when the threshold value (0.8394) is exceeded, the originally efficient *Resource* mode begins to fail, resulting in the decline of resource utilization efficiency. A large amount of waste and uneven distribution of resources begin to emerge, weakening the overall competitiveness of the industry, and aggravating the contradictory situation of the coexistence of resource shortage and surplus, and resulting in *Digagg*'s beneficial contribution to *Ingreen* being diminished. Li et al. (2023a) mentioned digital commerce may lead to resource waste and labor misallocation due to "excessive digitalization", which theoretically echoes the efficiency decline in the high misallocation stage mentioned above. It can be seen that the problem of *Resource* is a "double-edged sword" in the manner in which the digital business is developing. (3) Model (3) in Table 8 presents the empirical analysis results with *Inno* as the variable that crosses the threshold. When the first threshold value is exceeded by the level of *Inno*, although the effect of *Digagg* on *Ingreen* is still negative, the negative impact gradually decreases. Upon surpassing the second threshold value (10.1339), *Digagg*'s influence on *Ingreen* switches from negative to positive, with an impact coefficient of 0.194, showing a change from "beggar neighbor" to "neighbor as partner" (U-shaped change). It is evident that *Inno* is essential to a region's effective and coordinated growth. Industrial development should master the strategy of knowledge sharing and build an open knowledge-sharing system, promote the wide dissemination and efficient application of knowledge, and alleviate the inequality of knowledge distribution. To sum up, under the constraints of the above three threshold variables, the research findings of this work are further reinforced by the substantial non-linear effect between *Digagg* and *Ingreen*, which supports hypothesis 3.

TABLE 9 Robustness results.

Variables	*Ingreen*				
	(1)	(2)	(3)	(4)	(5)
Digagg	0.215***	0.224***	0.980***	0.198***	0.140***
	(6.80)	(6.99)	(10.33)	(6.17)	(78.48)
Marrket		0.515	0.259	−0.557	−0.190
		(0.89)	(0.42)	(-0.89)	(-1.33)
Open	0.225	0.652**	0.050	0.140	0.081
	(0.68)	(1.98)	(0.09)	(0.39)	(1.26)
Intercom	−0.123**	−0.314***	−0.092	−0.056	−0.032**
	(-2.03)	(-4.72)	(-1.47)	(-0.92)	(-2.23)
Human	−0.833***	−0.846***	−0.467***	−0.740***	−0.056**
	(-7.76)	(-7.97)	(-4.17)	(-6.69)	(-2.03)
cons	9.284***	10.164***	5.700***	8.303***	1.902***
	(9.82)	(10.89)	(5.60)	(8.44)	(7.61)
N	360	330	312	330	360

5.6 Robustness test

To evaluate the robustness of the empirical findings, this study performs a test of robustness on the findings of the influence of *Digagg* on *Ingreen* through five methods: reducing control variables, deleting samples according to time series, adjusting research samples, processing explained variables in the lag period, and replacing the measurement method of explained variables. Table 9 summarizes the test results.

First, there is a significant association between the research path and *Market* among the control variables on the impact of *Digagg* on *Ingreen*. This paper verifies whether there is an error and affects the robustness of the empirical results by removing *Market* control variable. Column (1) in Table 9 shows that the results are robust.

Second, this paper deals with the possible right truncation problem of the sample data. The relevant data of 2023 are excluded, and the research results are retested. The results

Column (2) in Table 9 show that the significance level and the coefficients of each variable do not significantly shift when compared to what was found in previous studies, which indicates that our research conclusion has high robustness.

Third, this work optimizes the research sample to better confirm the validity of the empirical findings and deletes the top two and bottom two regions in the degree of *Digagg*, which is equivalent to testing 26 provinces in China. The goal is to examine any potential bias that extreme values may have on the research findings and assess how reliable the empirical findings are. The adjusted analysis demonstrates that the explanatory variable coefficients and significance levels are not substantially different from the results of previous research.

Fourth, in light of *Digagg*'s time lag, this study chooses the explained variable with a one-period lag as a novel indication and tests it employing the benchmark regression model. The results in the previous text have passed the robustness test, and the model's regression coefficient and significance level match the study's findings in the previous section, corresponding to the result Column (4) in Table 9.

Fifth, this study substitutes the explained variable's measurement technique with the Data Envelopment Analysis (DEA) to measure *Ingreen*, re-examining *Digagg*'s influence on *Ingreen*. Column (5) in Table 9 displays the test results. *Digagg*'s regression coefficient and significance level match the benchmark regression findings in the earlier text, indicating that the results are robust. This result further confirms the stability and dependability of this paper's empirical analysis conclusions. In general, through these rigorous data processing and analysis methods, the research conclusions of this paper have a strong, persuasive, and applicable scope.

6 Conclusions and suggestions

6.1 Research summary

Ingreen is a flagship concept that promotes harmonious progress between environmental preservation and economic growth. It is essential for attaining sustainable development and is crucial in tackling climate change and advancing equity, stimulating economic vitality, and enhancing international competitiveness. Based on the synergy effect and innovation-driven development of *Digagg*, as well as the strategic demand for the objective of "inclusive green growth", China's provincial panel statistics from 2012 to 2023 are utilized in this study as the research sample and integrate threshold regression, mediating effect analysis, and panel fixed-effects models for comprehensive evaluation. The intrinsic connection and synergy mechanism between *Digagg* and *Ingreen* were deeply explored from three levels: the three main areas, the provincial regions, and the national level. This study innovatively incorporates *Resource* and *Inno* into the analytical framework of *Digagg* and *Ingreen*. Further, through theoretical analysis and empirical test results analysis, it reveals the influence mechanism of *Digagg* on *Ingreen*, verifies the above three hypotheses, and strictly tests the robustness of the research conclusions by using multiple measurement methods to ensuring the scientificity and credibility of theoretical discoveries and empirical results. The following elements primarily represent the research findings:

(1) *Digagg* may contribute significantly to regional *Ingreen* and demonstrate the geographical traits of "Western region > Central region > Eastern region". *Ingreen* considerably rises by 0.215 units with every unit increase in *Digagg*. After adopting two-stage least squares regression and difference GMM regression, sensitivity tests were further conducted through five measurement methods: reducing control variables, deleting samples based on time series, adjusting the range of research samples, substituting the explained variables, and applying lag processing to the explained variables. The results showed that the conclusion remained robust.

(2) *Digagg* has multi-level indirect effects on *Ingreen*. In the field of factor allocation, the efficient reorganization and precise matching of resources significantly enhance total factor productivity, laying an efficient foundation for green transformation. At the level of the effect of *Digagg*, the dual role of economies of scale and technological intensification reduces the resource consumption rate and pollution density per unit of output, restoring the equilibrium between ecological carrying capacity and industrial expansion methodically. In the technology-driven dimension, the network effect of knowledge spillover within industrial agglomeration and the multiplier effect of technological synergy promote *Inno* to upgrade from point breakthroughs to a systematic approach. These three mechanisms form a closed loop through the transmission path of "resource efficiency optimization - environmental pollution reduction - technological innovation leap", constituting the core mechanism for promoting *Ingreen* through *Digagg*.

(3) *Digagg* has a substantial threshold impact on *Ingreen*. In the initial stages of the digital industry's clustered development, the industry's agglomeration effect creates the benefit of economies of scale through the spillover effect of factors. Nevertheless, the rule of declining marginal gains will cause a considerable drop in the allocation efficiency of innovation factors when the level of industrial agglomeration is beyond the tolerable threshold. This phenomenon of diseconomies of scale will cause a structural imbalance in the quality of regional development. Ultimately, it places two restrictions on the process of green transformation and the enhancement of the economic system's inclusivity. When *Resource* is below the critical threshold, the marginal diminishing characteristic of the degree of resource misallocation will trigger a significant efficiency compensation effect. When further breaking through this threshold, the system will exhibit a lock-in effect of resource allocation, resulting in an exponential increase in the marginal inhibition rate. The digital sector itself is distinguished by its advanced technology, low energy consumption, lower emissions, and great added value. Its clustered development can form a powerful innovation ecosystem. With the continuous advancement of *Inno*, the degree of digital technology and conventional industries' interaction has increased, promoting

the transformation of production methods towards intelligence and greenness, the positive impact of *Digagg* on promoting *Ingreen* has become increasingly prominent.

6.2 Academic value

First of all, the theoretical dimension breaks through the research framework of the correlation effect between traditional industrial agglomeration and the green economy. By deconstructing the multi-dimensional mechanism of *Digagg* on *Ingreen*, it defies the understanding, especially in the level of pollution reduction and carbon reduction law of environmental governance enabled by digital technology. It provides an innovative theoretical paradigm for solving the "double lock" problem of economic growth and environmental constraints in the digital economy era. Secondly, it constructs an analytical model that simultaneously incorporates *Digagg* and *Ingreen* at the level of mechanism research. Based on the characteristics of China's provincial heterogeneity, the spatial econometric model is used to identify the differentiated action path of the development of *Digagg* under the differentiated situation of *Inno*, *Resource* and location conditions, which greatly enhances the spatio-temporal adaptability and policy enlightenment value of the research conclusions. Finally, systematically deconstruct the dynamic relationship among *Digagg* and *Inno*, identify the key nodes of policy optimization, and provide an empirical basis for regional differentiated governance.

6.3 Policy implications

(1) Based on the research conclusion, *Digagg* shows a heterogeneous characteristic of "Western region > Central region > Eastern region" for *Ingreen*. Based on this research conclusion, it is necessary to encourage the coordinated growth of *Ingreen* and the digital industry across all regions. Although the income of the digital industry in the eastern region is considerable, its contribution to *Ingreen* is relatively weak. For example, Shenzhen, as an important town of digital industry in the eastern region, although the digital industry is highly developed, environmental supervision still needs to be strengthened in some fields that combine traditional industries with digital industries, and the environmental pressure brought by the development of digital industries still needs to be further alleviated. Therefore, the eastern region needs to strengthen the environmental supervision of the digital industry and build a more rigorous environmental monitoring and evaluation system to guarantee that the growth of the digital sector will not have an adverse effect on the environment. At the same time, regions should focus on strengthening digital technology innovation capabilities, especially in sectors with high carbon emissions. Deep integration and low-carbon transformation of digital technology with key carbon emission fields such as power, industry, construction and transportation can reduce energy and resource consumption and alleviate the negative externalities of excessive agglomeration. On the other hand, the eastern region still needs to further improve the collaborative development mechanism.

For the central region, the industrial foundation is relatively weak, the industrial chain has not formed, and the scale of the core industries of the digital economy is small. For example, in Pingxiang, Jiangxi Province, although the traditional industry has a certain foundation, the combination of digital technology and industry is not close enough, and the number of enterprises related to the digital economy is small and the scale is limited, which is insufficient to support regional economic growth. Therefore, the western region needs to increase investment in 5G network, data center and other digital infrastructure, rely on traditional industries to promote disruptive *Inno* to strengthen industrial integration, and promote the green and low-carbon development of traditional industries. At the same time, the central region should also actively build a provincial digital collaborative platform, strengthen cooperation with the eastern and western regions, learn advanced experience, introduce high-quality resources, improve its digital industry level, and gradually narrow the gap with the developed regions.

The western region should give priority to improving digital infrastructure. Guizhou, Inner Mongolia, Gansu, and Ningxia have natural advantages in clean energy supply and are suitable for the construction of green computing power bases. By actively undertaking medium and high delay businesses in the eastern region, they can promote the transfer of high energy-consuming businesses, such as artificial intelligence model training in the eastern region to the west, thus promoting the development of renewable energy. Furthermore, nine national strategic emerging industrial clusters, such as new materials and biomedicine, and five national advanced manufacturing clusters, such as electronic information and aviation, can be strengthened to ensure their green and low-carbon characteristics. In terms of policy, we will implement inclusive digital development policies to ensure that digital growth benefits all members of society, especially vulnerable groups. In addition, the problem of the digital gap needs to be addressed to make sure that remote and rural areas can enjoy the fruits of digital development.

(2) Previous studies have found that *Resource* and *Inno* play indirect and nonlinear roles in the process in which *Digagg* affects *Ingreen*. This requires regions to focus on key industries, cultivate and introduce relevant enterprises, form industrial clusters, promote the coordinated development of the industrial chain's upstream and downstream, and improve *Resource*. Through the construction of 5G, cloud computing, and other new infrastructure, Zhejiang province has built a data sharing platform for the textile industry, promoted the digital transformation of the whole chain of traditional textile enterprises, and significantly improved the efficiency of resource allocation. At the same time, Suzhou Industrial Park will introduce leading enterprises in artificial intelligence and the Internet of Things, promote the

collaborative agglomeration of digital technology and manufacturing, accelerate the research and development and application of green and low-carbon processes, and build a number of national or regional green factories. Furthermore, give *Inno* priority and raise the conversion rate of technological achievements. In order to improve the technology conversion rate, Anhui province has set up an industry - academia - research innovation alliance for new energy batteries. The government supports enterprise research and development through green credit and special funds, and the related patent conversion rate has increased by 37% in the past 3 years. Thus, through scientific planning and reasonable arrangement of the direction and content of *Inno*, it is ensured that the research and development work closely revolves around improving *Resource* and ecological and environmental protection, ultimately achieving the goal of enhancing *Ingreen*.

(3) Based on the research conclusion, the impact of *Digagg* on *Ingreen* has nonlinear characteristics. Therefore, based on regional heterogeneity, the optimized development of *Digagg* should be based on regional endowment differences and construct a differentiated and characteristic development paradigm. In resource-scarce regions such as Shanxi, digital industrial agglomeration can reduce energy consumption by 12% by introducing blockchain traceability technology to optimize the coal industry chain, while the Yangtze River Delta region realizes spatial intensification of parks through the "industrial upstairs" mode, and energy consumption per unit GDP decreases by 18%. By drawing on and extracting typical experiences of *Digagg* in improving *Ingreen*, relying on regional resource endowments and industrial foundations, a full-cycle scheme design mechanism of "diagnosis - adaptation - optimization" is established to improve industrial linkage between different locations in terms of coordination, interoperability, and operability. Build an industrial ecosystem in a three-dimensional way, achieve a cluster leap through the joint construction of infrastructure, sharing of data elements, co-cultivation of innovation platforms, and other measures to achieve cluster leap, further release the multiplier effect of digital technology, form a virtuous cycle of "green innovation - efficiency improvement - fair sharing". By coordinating the manufacturing sector and digital industry cluster, the Guangdong - Hong Kong - Macao Greater Bay Area facilitates the efficient enhancement of energy efficiency of Midea Group's air conditioning production line, and achieves the Pareto optimality of inclusive growth and ecological benefits.

6.4 Limitations

Although this study quantifies the mechanism by which *Digagg* affects *Ingreen* and makes corresponding suggestions based on reality, there are still certain restrictions, which are important topics for additional study, including the following: (1) This paper includes 30 provinces in China into the research field of vision, and presents a comprehensive picture of *Ingreen* in the country from a macro perspective. This research scale can grasp and understand the general trend and basic model of *Ingreen* in different regions of the country. However, to have a deeper understanding of the specific situation and regional differences of *Ingreen*, future studies will try to transfer the focus of the study from the province to the city, particularly in important cities with thriving economies and rapidly growing digital businesses. Through gathering and examining micro-data from these cities, the actual situation of *Digagg* and its specific impact on *Ingreen* can be portrayed more accurately. Such fine-grained research helps identify the unique needs and challenges of different cities in terms of digital industry development and green growth. (2) In the subsequent investigation, to more thoroughly examine the "black box" mechanism of *Digagg* on *Ingreen*, a series of key variables, including innovation capacity, policy support, market environment, and social capital, can be utilized to construct a multi-dimensional analytical framework. Through the comprehensive consideration of these variables, the complex relationship between *Digagg* and *Ingreen* can be more accurately described, and how different factors interact can be revealed to further affect the quality and sustainability of economic growth, providing a theoretical basis for formulating more accurate policy measures.

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Author contributions

KL: Conceptualization, Data curation, Methodology, Software, Writing – original draft, Writing – review and editing. YQ: Conceptualization, Formal Analysis, Resources, Validation, Writing – review and editing. JZ: Writing – review and editing, Data curation, Formal analysis. CL: Funding acquisition, Investigation, Methodology, Supervision, Visualization, Writing – review and editing. JX: Methodology, Visualization, Writing – review and editing.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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Supplementary material

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