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THE IMPACT OF DIGITAL ECONOMY ON REGIONAL GREEN AND HIGH-QUALITY ECONOMIC DEVELOPMENT IN CHINA

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Abstract. With the rapid advancement of digitization, the duty of the digital economic climate in advertising regional economic growth is ending up being progressively noticeable. Nonetheless, there is relatively little research study on how the digital economic situation specifically impacts regional environment-friendly and high-quality financial growth (RGED). This study utilizes provincial panel data from 2013 to 2020 in China to empirically assess the effect of the digital economic environment and validates its effect with a fixed impacts model. The study has produced four unique and important findings for: firstly, the effect of the digital economic climate on RGED exhibits nonlinear qualities; Second of all, RGED is significantly influenced by the "∩ - formed" effect of the advancement of the digital economic situation and the degree of industrial digitization; Finally, the influence of digital framework and digital industrialization on RGED exhibits a considerable "∪-shaped" pattern; Fourth, the digital economic situation indirectly advertises the growth of RGED by enhancing human funding and updating commercial structure. These conclusions offer beneficial plan support for relevant financial entities to achieve RGED.

Keywords: digital economy, green and high-quality economic development (RGED), human capital, fixed-effect model.

JEL Classification: O10, O53.

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1. Introduction

The digital economic situation, as an arising variable of manufacturing, has a significant influence on promoting financial growth in nations around the globe (Ding et al., 2021). The digital economy belongs to a series of economic tasks, which are essential production components of digital knowledge and information features. Digital facilities work as an essential host, and the reliable application of details and information and communication technology (ICT) has value in improving performance and refining economic structure (Li & Zhao, 2023). The digital economy encompasses several key industries that leverage technology to drive innovation and efficiency. Key examples are Amazon, Alibaba, and JD.com, which revolutionize online retail. In the fintech sector, companies like PayPal, Ant Financial, and Stripe enhance financial services through digital payments, online banking, and blockchain technology. Firms specializing in artificial intelligence (AI), such as OpenAI, advance machine learning, AI-generated content (AIGC), and robotics, applying these technologies across various domains. These industries collectively drive the digital economy forward, fostering significant technological advancements and operational efficiencies. Taking digitized knowledge and information as crucial production factors is basically a symptom of digitalization and automation; using information and interaction technology to advertise the optimization of economic structure is essentially the process of commercial digitization. Therefore, digital facilities, digital automation, and industrial digitization are widely regarded as the core parts of the digital economy (Chen et al., 2023b). In the context of the digital economic climate period, information has actually become an emerging aspect of production and has been integrated right into the system of production aspects. This emerging variable is closely integrated with typical manufacturing elements such as labor, resources, land, and resources. This combination can totally utilize the benefits of large heap and unrestricted supply, breaking through the limitations of conventional manufacturing consider terms of complete amount; On the other hand, it can likewise significantly boost the application performance of traditional manufacturing aspects with multiplier impacts, opening up brand-new feasible paths for environment-friendly development (Ionescu et al., 2023). Digital industrialization promotes economic and social development in the direction of higher efficiency, greener, and higher quality through optimizing industrial structure, providing opportunities for "creative destruction" for green development (Li & Zhao, 2023).Through the integration and innovation of industries, industrial digitization will bring about a series of new models and business forms for emerging industries, which is conducive to continuously expanding the boundaries of industry penetration and integration, thus contributing greatly to green development (Olczyk & Kuc-Czarnecka, 2022). Overall, the advancement of the digital economy can trigger profound transformations across various dimensions, ranging from the factors of production to productivity to production relations. It offers a more efficient operational model, a more resilient developmental framework, a more sustainable mode of production, and a more contemporary approach to governance, thereby fostering regions' comprehensive green and high-quality development.

A number of research efforts have discovered the effect of the digital economy on high-grade local economic advancement. These studies show that the digital economic climate can have a considerable favorable impact on regional economic development. As an example, Dou and Gao (2022) recommended that the digital economic climate has considerable network surfaces and economic situations of range, which can break through information crookedness and minimize transaction prices. On top of that, the digital economic situation can optimize business processes, give a favorable setting for advancement, and offer networks for business to access key resources (Gebauer et al., 2020). Wen et al. (2021) think that the advancement of the digital economic climate can supply a pathway for high-grade financial advancement by promoting digital change of ventures, digital advancement of sectors, and institutional innovation. Goldfarb and Tucker (2019) specified that the digital economic climate has altered typical financial designs and driven the process of premium economic growth. Additionally, the integrated application of digital modern technology can improve the effectiveness of environment-friendly economic climate, motivate energy conservation and exhaust decrease work, and contribute to lasting advancement (Ren et al., 2021). The digital economic situation can enhance the efficiency of business source application, upgrade government environmental regulative measures, and enhance social environmental understanding (Kong & Li, 2022). These research studies emphasize the positive influence of digital financial growth in promoting top quality economic growth and progressing sustainable growth.

Despite these positive impacts, scholars also express concerns about the potential limitations of digital economy development. Some argue that excessive government intervention or managerial emphasis on digital economy development may not necessarily translate into increased output in terms of green technology innovation for local enterprises (Švarc et al., 2020). Additionally, complexities arising from extensive digital infrastructure coverage may hinder effective governance and the rational utilization of digital assets by local firms for green technology innovation (Zhou et al., 2020). Even though the development of the digital economic climate improves the influence of industrial upgrading, numerous diversifications still exist (Li & Zhao, 2023). Moreover, problems like over – dependence on digital modern technologies and a lack of digital – experienced personnel might avoid the digital economic situation from efficiently upgrading the commercial structure (Gao & Sun, 2022). As a result of the power rebound result, the growth of the digital economy may lead to a boost in carbon emissions (Xiao et al., 2023). These study outcomes highlight the requirement of performing a lot more complete research study on the complex link between the digital economy and regional environment-friendly, high-quality economic development (RGED).

Although that previous study has thoroughly examined the connection between the digital economy and regional high-quality financial and eco-friendly growth, there are still consistent controversies and limitations within the existing research study: ① The influence of the digital economy on RGED continues to be a debatable subject (Zhang & Yin, 2023). That is to state, whether the digital economic climate promotes or hinders RGED remains unpredictable. ② The majority of the previous research has presumed a linear link between the digital economy and RGED, while disregarding the possible non-straight connections (Luo et al., 2023). ③ RGED stresses the consolidation of sustainable practices and eco-friendly modern technologies right into economic techniques to get to economic prosperity and environmental sustainability (Liu et al., 2022). Nonetheless, a number of the existing studies mainly focus on the digital change of business and the optimization of industrial structure (Yousaf et al., 2021; Gupta et al., 2020). They pay more focus to the established passions and overlook the critical aspects of eco-friendly advancement. In this paper, by utilizing the panel information of Chinese provinces from 2013 to 2020, the development level of the digital economic situation in different areas is reviewed. We adopt a repaired-results model to evaluate the influence of digital economy growth on RGED. On the other hand, we also check out the feasible non-linear organizations in between the digital economy and RGED. Additionally, to make up for the previous neglect of eco-friendly eco-friend development, this study takes both economic and ecological advantages into account when determining RGED. Particularly, based upon input indicators, preferred outcome indications, and undesired outcome indications, an undesired-result super-effectiveness slack-based model (SBM) is established to calculate the degree of RGED.

In contrast to existing literature, this paper makes the following unique contributions:

① Although previous research has presumed a linear connection between the digital economy and RGED, this research study discovers a non-direct, inverted -U-shaped link between them. This point of view enhances the academic structure concerning the partnership between the digital economic climate and economic development.

② In order to offset the disregard of eco-friendly advancement in previous research, this short article takes both financial and ecological benefits into account when measuring RGED, thus conquering the limitations of one-dimensional measurement of the digital economic situation.

③ The theoretical framework of this article checks out the moderating impacts of human capital and commercial structure updating to get relevant research results.

2. Theoretical background and research hypotheses

The digital economic, which has actually established in two essential stages – originally making use of data to boost traditional industries and afterwards relocating in the direction of the automation of data – advertises high-quality financial progress and highlights the principles of eco-friendly and low-carbon in economic growth (Sabli et al., 2023). The first stage is the primary stage of the digital economy: data empowering traditional industries. Basic digital industrialization (1.0) primarily refers to a narrowly defined segment of the information industry, encompassing data infrastructure, digital information manufacturing and so on. After the relative perfection of basic digital industrialization, the industrial digitization of traditional industries began; traditional industries improved production efficiency and quality by applying digital information technology, and the business processes and data resources of traditional industries achieved deep integration (Qi et al., 2023). The second stage is the digital economy upgrade stage: data are industrialized. With the digitalization process of traditional industries reaching a specific scale, the digital economy will gradually move toward the era of digital industrialization 2.0, where industrial data are used as a resource element for horizontal empowerment and vertical integration empowerment, which will significantly improve production efficiency (Chen et al., 2023b). Presently, driven by the rapid – paced development of the information technology industry, the digital economic situation in significant countries around the globe has actually moved from the digital automation 1.0 age to the phase of actively advertising industrial digitization (Li & Zhao, 2023).

RGED can be usually divided right into three main phases. The preliminary stage is the environmental pollution stage, throughout which the emphasis is mostly on dealing with ecological issues and boosting environmental top quality with the support of environmental protection plans and the decrease of toxin discharges (Wan & Su, 2023). The second stage is the resource-saving stage. After the environmental protection work is gradually effective, people begin to pay attention to the economic utilization of resources. This phase mostly centers on the thrifty use of energy, materials, and various other components, and developments the advancement of a round economic situation (Guo et al., 2023; Lin et al., 2024). The third stage is the stage for the building and construction of ecological civilization. With socioeconomic development and scientific and technological progress, people have realized that the ecosystem is the basis for human survival and development. This stage mainly focuses on protecting and restoring ecosystems and promotes forming a people-centered, coordinated, symbiotic ecological civilization system (Dou & Gao, 2022).

2.1. Digital economy and RGED

The digital economy is putting in a transformative effect throughout various sectors and regions. It promotes high-quality financial development by enhancing digital framework, driving the digitization of industries, and helping with commercial digitization. Additionally, it underscores the importance of incorporating environment-friendly and low-carbon concepts as necessary parts for achieving sustainable growth. The digital transformation moved by the digital economy can be seen as a procedure pertaining to technological alterations in all economies and cultures (Olczyk & Kuc-Czarnecka, 2022). Economic theory (Cobb & Douglas, 1928), neoclassical theory (Solow, 2000), endogenous development theory (Romer, 1990), and transformative development theory (Freeman & Louçã, 2001) all acknowledge that technical change is important for economic development. In particular, endogenous growth theory emphasizes that technical adjustment is of fantastic significance as a key driver for financial growth. Because of this, the present empirical research study reveals that the digital economy is crucial in promoting high-quality economic development. Some researches point out that the digital economic climate has changed organization processes and purchase patterns by digitizing information and communication modern technology and contemporary information networks (Li & Zhao, 2023). Additional research suggests that the digital economy promotes digitization by promoting production, management, and consumption and changes the economic structure and the way economic value is created (Dou & Gao, 2022; Higón, 2012). Internet access and mobile application advancements enable firms to swiftly adjust to volatile economic climates, including evolving consumer demands (Bełz et al., 2019; Olszewska, 2020; Olczyk & Kuc-Czarnecka, 2022). It can be seen that the digital transformation within the digital economy has become an important influencing factor in the growth strategy of enterprises. RGED demonstrates a high-quality state that encompasses a broader range of quality categories compared to economic growth. The theoretical principles of high-quality development are evidenced by improving supply efficiency, achieving fair development, ecological civilization, and human modernization (Koloszko-Chomentowska, 2015). This research contends that RGED ought to center on the quality of economic development and take into account both ecological environmental protection and green development.

The expansion of the digital economy may lower pollution emission and resource use, alleviate stress on conventional economic frameworks, boost market dynamism, and hasten urban digital transformation to improve residents' living standards (Pouri, 2021). Owing to the prevalence and penetrability of digital technology in the digital economy, it can be applied extensively in various industries and enterprises, which promotes the effective allocation of production resources and boosts total factor productivity. From the micro level, the advancement of the digital economy drives digital transformation in businesses. From the middle level, it promotes the digital construction of industrial clusters, finally spreading to the digital innovation of the economic system at the macro level, which is a change to the traditional economic model (Goldfarb & Tucker, 2019). Therefore, from the perspective of enterprise digital transformation, industrial digital development, and digital economic system innovation, a progressive development mode of "business ecology-digital empowerment-high-quality development" can be constructed, providing a development path for RGED. As a new production factor, data are highly integrated with traditional production factors, including labor, capital, land, and resources (Popescu et al., 2019). The multiplier effect brought by this combination not only improves the utilization efficiency of traditional production inputs, but also provides a practical and achievable way to achieve RGED (Olczyk & Kuc-Czarnecka, 2022). Meanwhile, some scholars have pointed out that the digital economy has brought about a new economic field and social development environment that relies on digital technology. Based on this, the development of the digital economy has greatly influenced the social development of the digital economy, providing a solid foundation for achieving the goals of high quality and efficiency, adhering to low-carbon economy and development. Data indicates that digital infrastructure, digital industrialization, and industrial digitization are important factors driving the growth of the digital economy. This paper will explore how the digital economy influences RGED by examining three critical factors.

(1) Digital infrastructure: Digital infrastructure encompasses the array of physical and virtual assets essential for fostering the digital economy, digital society, and information society. It includes key components such as digital platforms, cloud computing services, and the industrial Internet, alongside associated technologies and services. These elements are specifically designed to deliver high-speed, dependable, secure, and sustainable capabilities for digital communication and information processing (Chen et al., 2023a). The development of the digital economy has put forward many stricter requirements for digital infrastructure because the development of the digital economy is closely intertwined with online media. However, the "last mile" network infrastructure established in impoverished areas is still very serious at present (Xie et al., 2023). When digital infrastructure coverage is insufficient, local public assets may be unable to meet the development needs. This situation is not conducive to the rational use of digital assets by enterprises in the region for green technological innovation (Botrić & Božić, 2021), which is also detrimental to RGED. The current digital infrastructure construction also faces multi-dimensional challenges such as energy saving, cost reduction, security, openness, development, and governance (Cong et al., 2022; Koseoglu et al., 2019; Wang & Yin, 2022), which inhibits RGED. With the progression of the digital economic situation, it is bound to accelerate the modernization process of conventional industrial infrastructure, enhance the growth of digital framework, assist in the digital makeover of typical markets, and improve the general performance of sectors (Wang et al., 2022). Furthermore, digital infrastructure has the capability to increase the productivity of manufacturing consider different industries. This, consequently, fine-tunes the labor department and expertise amongst sectors, promotes the optimization and upgrading of the commercial framework, activates knowledge spillover results (Karman et al., 2020), and thus adds to the development of regional green economy (RGED).

(2) The uneven and poor evolution of digital modern technology is prone to create the scarcity of resources, like Internet-related tools, in less-established areas. This situation generates "tool exclusion" (Botrić & Božić, 2021), causing structural problems in digital industrialization. Digital automation consists of services and products arising from digital modern technology, such as digital information manufacturing, software services, and the Internet field. Industry segmentation makes it apparent that digital industrialization varies significantly among industries. The software and Internet industries continue to make up a larger proportion of digital industrialization, while the digital information manufacturing and telecommunications industries are gradually losing relative importance. Digital technical talents are the key to digital industrialization. Economically developed regions have abundant and advanced talents and technical resources; however, digital technical talents are more inclined to improve efficiency, which weakens innovation motivation and necessary innovation capabilities (Wiblen & Marler, 2021), negatively affecting green technology innovation and RGED. The sluggish development of environment-friendly technology advancement and digital industrialization in economically backwards regions is mostly as a result of the lack of digital technological experts. For that reason, boosting digital proficiency contributes to bridging the digital divide and ensuring the secure advancement of the digital economic situation (Wang et al., 2022). At the same time, making it possible for ventures to boost sychronisation effectiveness in environment-friendly practice and advertising eco-friendly modern technology innovation are advantages that enterprises can appreciate from digital facilities. Additionally, digital industrialization, a sector emerging from the advancement of digital innovation, acts as the foundation and requirement for driving the upgrading of the commercial framework. The improvement of digital modern technology and the improvement of digital proficiency permit standard suppliers to swiftly shift to mid-high-end production and blend with the solution industry, therefore facilitating industrial restructuring (Liu & Chen, 2021), and additionally promoting high-high quality regional economic development.

(3) Industrial digitalization: With the digital economy at its core, commercial digitalization stresses the assimilation of standard industries and digital modern technologies. This entails the digital upgrading and transformation of all elements within the whole commercial chain. Industrial digitalization advertises industrial combination and boosts advancement, driving ahead the adjustment of the commercial structure (Zhang et al., 2022). The application of digital technology breaks down technology obstacles and cuts down purchase prices. Because of this, it advertises green technology advancement in resource-based business by motivating teamwork (Shafi et al., 2022). The region's green and high-quality development relies on integrating industries, ongoing refinement and promoting industry upgrading, and innovation of green technology; nevertheless, overuse of digital technology can result in excessive industrial digitalization, leading to "information overload" for businesses, which negatively affects decision-making and increases errors (Fleischer & Wanckel, 2023).

According to the foregoing analysis, it can be concluded that the growth of the digital economic climate can speed up the innovation of conventional industrial facilities, drive the continual improvement and improvement of the commercial framework, motivate the integration and development of markets, and create knowledge spillover influences. On top of that, it has the ability to enhance the accumulation of expertise in environment-friendly modern technology development and promote the development of environment-friendly modern technology. Yet, problems like the administration effectiveness of new funds, information security, and excessively fast digital automation will maintain turning up as digital modern technology proceeds. The problems faced by digital economic development and the costs will exceed the benefits, negatively affecting RGED. Therefore, we propose the following research Hypotheses:

H1: *There is a "∩-shaped" relationship between the level of digital economic development and RGED.*

H1a: *There is a "∪-shaped" relationship between digital infrastructure and RGED.*

H1b: *There is a "∪-shaped" relationship between digital industrialization and RGED.*

H1c: *There is a "∩-shaped" relationship between industrial digitalization and RGED.*

2.2. Human capital and RGED

Human capital plays an important duty in advertising financial growth in the digital economic climate. This is highlighted by its favorable connection with the development of digital innovations, the growth of high-end sources, and its intermediary feature in accomplishing high-quality financial development. Advancing digital innovations enhance knowledge and automation; with boosting work automation, there is an expanding requirement for skilled workers and premium human resources, creating higher production process effectiveness (Salam et al., 2019). The digital economic climate is defined by quick-paced development. Generally, it demands substantial investments in both modern technology and human resources to attain a lasting range. Consequently, the development of the electronic economic climate generates an enhancement in high-end sources, such as sophisticated modern technologies and the human capital needed to support their combination and usage (Schumacher & Sihn, 2020). The appearance of information technologies has reduced the cost of info gain access to and provided more possibilities for the enhancement of human capital.

Furthermore, it enables individuals to gain knowledge irrespective of time and location, particularly benefiting students in remote areas who can access top-tier tutoring, thereby improving human capital quality across various regions (Liu & Chen, 2021). Furthermore, RGED exhibits positive associations with factors such as human capital, the level of government intervention, and the rate of urbanization (Zhuang & Pan, 2022). During digital transformation, enterprises can reinforce their resilience by improving human capital (Al-Refaie et al., 2020). Hanushek and Woessmann (2012) found that better education leads to faster economic growth. Di Maria and Stryszowski (2009) believe that middle and high-level human capital can promote economic development. Furthermore, Prasetyo and Kistanti (2020) examined the link between regional economic sustainability and human capital. Their study results emphasize the vital function that human capital plays in promoting economic growth, through both direct and indirect means. Thus, the following research study theory is advanced:

H2: *The development of the digital economy generates a positive influence on human capital levels; human capital acts as a mediator in the effect of digital economic development on RGED.*

2.3. Industrial structure upgrading and RGED

The digital economic climate plays an essential catalytic role in advertising lasting economic growth. It promotes commercial architectural makeover, consequently enhancing eco-friendly complete factor efficiency. This procedure consists of enhancing the building of digital facilities, accelerating the process of digital automation, and promoting commercial digital makeover. These key elements collaborate to optimize source allotment, improve technological efficiency, and attain economic situations of scale, thus promoting high-quality economic advancement. The digital economic climate is considered as the core driving force for lasting financial development, and it plays an important intermediary function in boosting environment-friendly overall variable productivity via industrial structure change (Li & Zhao, 2023). Study has actually shown that digital framework, digital industrialization, and commercial digitization are crucial indications for gauging the degree of advancement of the digital economic climate (Liu & Chen, 2021). The digital economy can assist in the updating of standard industrial facilities, thus improving the total efficiency of commercial growth (Banga, 2022). Driven by digital automation and industrial digitization, the digital economic situation has not only enhanced emerging industries, but likewise changed standard markets, reshaped the core structure of commercial framework, and achieved the updating and optimization of industrial structure (Tashenova et al., 2020). By leveraging digital technology, the traditional manufacturing industry can be propelled toward mid-to-high-end manufacturing, while the integration of manufacturing and service industries can be promoted. Consequently, the industrial structure is upgraded (Liu & Chen, 2021). Industrial digitization can promote the integrated development of industries, promote industrial innovation, and lead to a more optimized and efficient industrial structure (Schumacher & Sihn, 2020). Industrial structure upgrading has improved the total factor productivity in terms of resource allocation efficiency, technical efficiency, and scale efficiency, thereby promoting RGED (Li & Zhao, 2023). Furthermore, upgrading the industrial structure is critical for the digital economy to promote environmental quality improvement. The digital economy can reduce environmental pollutants directly and indirectly optimize industrial structures (Li & Wang, 2022). Therefore, the Hypothesis 3 is proposed:

H3: *Digital economic development positively affects industrial structure upgrading; industrial structure upgrading mediates the impact of digital economic development on RGED.*

Figure 1 presents this article's research framework.

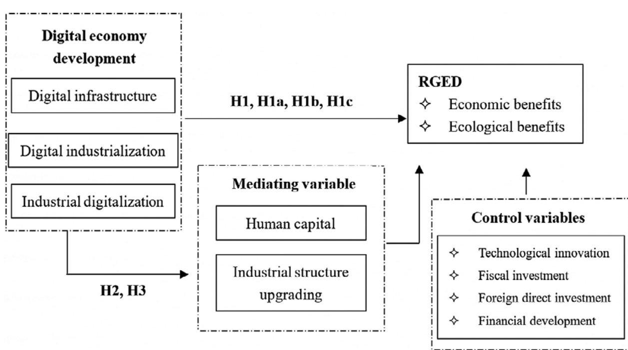


Figure 1. Theoretical framework

3. Methodology

3.1. Measurement models

We constructed a regression model where regional green economic development (RGED) serves as the dependent variable and the development of the digital economy acts as the independent variable. This model was designed to investigate the influence of the growth of the digital economy on RGED. The model can be presented as follows:

$$ghd_{it} = \alpha + \beta_1 de_{it} + \sum_m x_m + \varphi_i + \eta_t + \mu_{it}. \quad (1)$$

For convenience, the parameters in equation (1) are summarized in Table 1.

Table 1. Summary of the notations

Notations	Definitions
ghd	the index of regional high-quality economic development
de	the index of digital economic development
ξ	control variables, including technological innovation, fiscal investment, foreign direct investment, and finance development
φ	the entity fixed effect
η	the time fixed effect
μ	the disturbance term
α	the intercept term
β_1	the coefficient of digital economic development, signifying its influence on RGED
subscript *i*	region
subscript *t*	year

By employing the mediating effect model formulated by Mackinnon et al. (1995), our study adopted a sequential regression method to empirically investigate whether human capital and the upgrading of the industrial structure act as mediators in the relationship between digital economic development and RGED. The mediating-effect model is shown as follows:

$$\pi_{it} = \gamma + \gamma_1 de_{it} + \sum_k x_k + \varphi_i + \eta_t + \mu_{it}; \quad (2)$$

$$ghd_{it} = \alpha + \beta_1 de_{it} + \beta_2 \pi_{it} + \sum_m x_m + \varphi_i + \eta_t + \mu_{it}, \quad (3)$$

where π_{it} refers to the index of human capital or industrial structure enhancement for region *i*in year *t*; γ denotes the intercept term; γ_1 denotes the coefficient of digital economic development, signifying its impact on human capital or industrial structure upgrading; β_2 is the coefficient of human capital or industrial structure upgrading, indicating its impact on RGED; the remain parameters are the same as in Table 1.

3.2. Variables

3.2.1. Explained variable

RGED is the explained variable. Green and high-quality development focuses on innovation-driven growth and improvements in production efficiency to foster the green transformation of the economic structure, thereby achieving high-quality green development. This mirrors the dialectical consistency between economic advancement and environmental sustainability. From a macro perspective, green and high-quality advancement, on the one hand, entails the restructuring of the economic structure. This restructuring consists of the greening procedure of commercial fields, the modern elimination of industries with high contamination and power intake, and the growth of tidy and high-tech sectors like new power. These techniques aim to eventually accomplish a decrease in the discharge of toxic wastes, a sustained renovation in the eco-friendly environment high quality, and an increase in the environmental bring ability. On the other hand, eco-friendly and high-grade growth includes the change of the financial growth setting, which needs innovation-driven growth to eliminate the dilemma of too much source intake and environmental pollution brought on by over-reliance on investment-driven advancement. These methods increase the improvement of production efficiency along with source appropriation efficiency, and achieve the decline in contaminant exhausts and the decrease of power usage. This paper considers economic and environmental advantages when gauging RGED utilizing a SBM with undesirable outputs and super-efficiency, as described in Oh (2010). This design relies upon an input index, a wanted output index, and an undesirable result index. In comparison to traditional DEA models, the SBM design with unwanted output not only averts the mistakes from radial and angular measurements but likewise thinks about the impact of unwanted output factors throughout manufacturing, providing a much more exact representation of efficiency evaluation. The Equation is represented as:

$$\rho = \min_{\lambda,\bar{x},y^g,y^b} \frac{\sum_{i=1}^{m} \frac{\bar{x}_t}{x_{i0}}}{\frac{1}{s_1+s_2}\left(\sum_{r=1}^{s_1} \frac{\bar{y}_r^g}{y_{r0}^g} + \sum_{k=1}^{s_2} \frac{\bar{y}_k^b}{y_{k0}^b} + \right)}. \quad (4)$$

The specific input–output variables are intuitively shown in Figure 2.

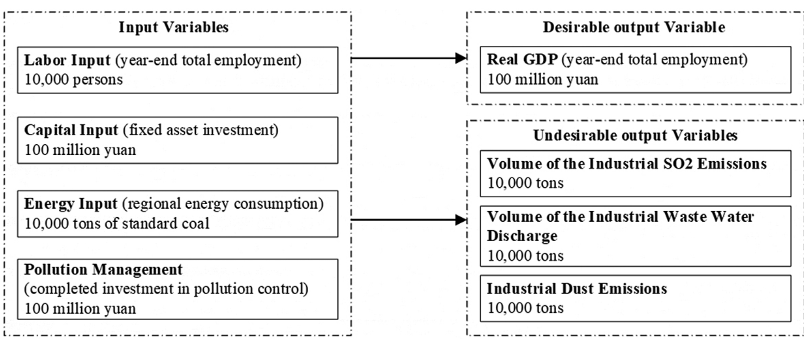


Figure 2. Input–output variables

In Equation (4), the variables $\overline{x}$, $\overline{y_r^g}$ and y_k^b denote the projected or target values for the evaluation unit's input-output parametersCorrespondingly, x_{i0}, y_{r0}^g, and y_{k0}^b represent the original values. The input index encompasses several factors: (*1*) *Labor Input*. Measured by the total employment at the end of the year. (*2*) *Capital Input*. Represented by the total societal fixed asset investment. (*3*) *Energy Input*. Corresponds to the total regional energy consumption. (*4*) *Pollution Management*. Assessed based on investments in industrial pollution control. The output index is divided into: (*1*) *Desirable Output*. Represented by the regional GDP. (*2*) *Undesirable Output*. Includes industrial SO2 emissions, industrial wastewater discharge, and industrial dust emissions.

3.2.2. Core explanatory variable

This study takes the growth of the electronic economic situation as the major informative variable. The digital economic situation encompasses economic activities which rely on digitized expertise and information as important manufacturing factors, like modern information networks. Digital facilities act as a vital provider, and the effective use of ICT is of fantastic importance for boosting productivity and advertising the upgrading of the economic framework. Using digitized understanding and info as crucial production aspects is essentially electronic industrialization, and making use of electronic technologies, such as ICT, to optimize the economic structure is basically industrial digitization. Thus, electronic infrastructure, electronic automation, and commercial digitization are essential components of the electronic economy. Theoretically, the essential prerequisite for the development of the electronic economy is the building of electronic facilities. Only on this basis can electronic industrialization and the digitization of sectors be understood (Zoppelletto & Orlandi, 2022; Guo et al., 2024). This implies that the digital economic climate can be divided into 3 unique components. Empirically, drawing from a series of existing literary works (Bukht & Heeks, 2017; Ma & Ning, 2020; Tian et al., 2023), the electronic economic development index could be built from three dimensions: digital infrastructure, digital industrialization and industrial digitalization. This research develops an index system for reviewing the development of the electronic economy. It consists of digital facilities, electronic industrialization, and industrial digitization to measure the growth level of the local electronic economy. This system consists of 3 primary indexes – digital infrastructure (*debas*), digital industrialization (*dein*), and industrial digitalization (*inde*) – along with 12 secondary indexes, detailed in Figure 3. The entropy TOPSIS (technique for order of preference by similarity to ideal solution) method belongs to the objective assignment method, and its starting point is to determine the weight coefficients based on the degree of difference between the values of the evaluation indicators. Compared with the subjective assignment method, the entropy TOPSIS method eliminates human bias, allowing for an objective assessment of each indicator's relative significance, and is extensively utilized in the objective allocation within social and economic domains (Herrera et al., 2001). Therefore, this paper weights all indices by the entropy TOPSIS method.

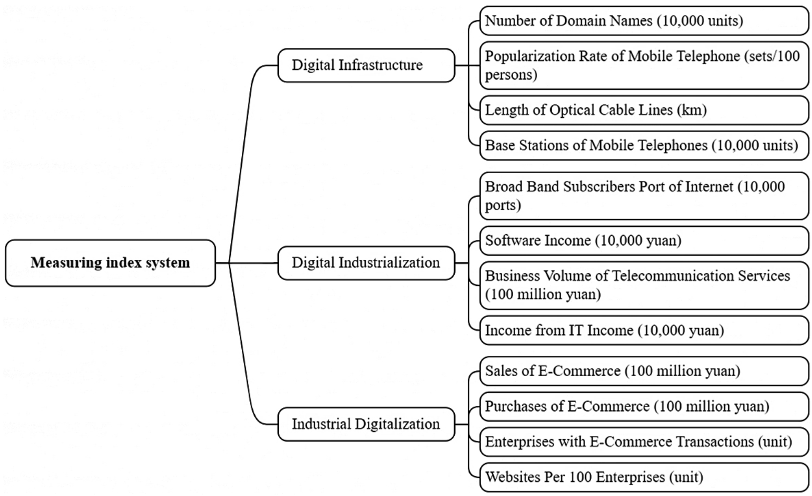


Figure 3. Measuring index system of digital economic development

3.2.3. Mediating variables

From our prior analysis, we recognized human capital and industrial structure upgrading as mediating variables.

(1) Human capital (hum): Human capital consistently impacts economic growth. In line with the approach put forward by Mandelman and Zlate (2012), Human capital is determined by the ratio between high skilled and low skilled individuals. The high skilled individuals showcased refer to those who have at least a university degree, while low skilled individuals refer to those with relatively lower levels of education.

(2) Industrial structure upgrading (*isu*): This study adopts the indicator of industrial restructuring speed to measure industrial structure upgrading. A key consideration in this study when assessing shifts in industrial restructuring is the pace at which industrial restructuring occurs. Furthermore, we employ a modified Lilien index to quantify the speed of regional industrial restructuring. We calculated the rate at which the workforce is redistributed across various sectors (Garonna & Sica, 2000). This process is denoted as:

$$isu_{it} = \sqrt{\sum_{n=1}^{3} \theta_{int} \left[\ln\left(\frac{z_{int}}{z_{int-1}}\right) - \ln\left(\frac{Z_{it}}{Z_{it-1}}\right) \right]^2} . \quad (5)$$

In Equation (5), the variable isu_{it} represents the speed of industrial restructuring in region i during year t. The parameter θ_{int} is the mean proportion of workers employed in industry n relative to the total employment of region i for both year t and year $t-1$. The variable z_{int} denotes the number of employees in industry n during year t. Z_{it} is defined as the total employment at the national level for year t, with n specifying the particular industry. In the modified Lilien index, the variables are established between the periods t and $t-1$. As the index increases, it indicates a more rapid pace of industrial restructuring (Garonna & Sica, 2000); that is, the higher the level of industrial structure upgrading.

3.2.4. Control variables

In the regression model, variables influencing RGED are designated as control variables. These encompass technological innovation (*innov*, assessed by the ratio of regional patents granted to national patents granted), fiscal investment (*gfi*, determined by the share of local general public budget in GDP), foreign direct investment (*fdi*, calculated by the share of foreign direct investment in GDP), and financial development (*fina*, which measures digital financial inclusion, evaluated using the digital financial inclusion index created and published by the Institute of Digital Finance at Peking University). Table 2 presents the specific definition of each variable.

Table 2. Variable description

Category	Name	Symbol	Definition
Explained variable	RGED	*ghd*	Regional green and high-quality development comprehensive index
Explanatory variables	Digital economy development	*de*	Overall index of regional digital economy development level
	Digital infrastructure	*debas*	Regional digital infrastructure composite index
	Digital industrialization	*dein*	Regional digital industrialization composite index
	Industrial digitalization	*inde*	Regional industrial digitalization composite index
Mediating variables	Human capital	*hum*	$\frac{\text{high}-\text{skilled talents}}{\text{lower}-\text{skilled talents}}$
	Industrial structure upgrading	*isu*	Regional industrial structure upgrading composite index
sControl variables	Technological innovation	*innov*	$\frac{\text{regional patent grants}}{\text{national patent grants}}$
	Fiscal investment	*gfi*	$\frac{\text{local general public budget}}{\text{GDP}}$
	Foreign direct investment	*fdi*	$\frac{\text{foreign direct investment}}{\text{GDP}}$
	Financial development	*fina*	Regional digital finance development composite index

3.3. Datasources

The data were collected from a selection of sources, such as the China Statistical Yearbook (2021) (National Bureau of Statistics of China, 2021b) China Labor Statistical Yearbook (2021) (National Bureau of Statistics of China & Ministry of Human Resources and Social Security of China, 2021) China City Statistical Yearbook (2021) (National Bureau of Statistics of China, 2021a), and different rural statistical yearbooks. The moment range covered is from 2013 to 2020. This study analyzes 30 provinces in landmass China. The Tibet Autonomous Area is not included as a result of insufficient data. Table 3 shows descriptive statistics of variables.

Table 3. Descriptive statistics of variables

Variable	Obs	Mean	Std. Dev.	Min	Max
ghd	240	0.3371013	0.2263125	0.1393646	1
de	240	0.62757	0.105016	0.518805	0.969663
debas	240	0.1806521	0.0263335	0.143372	0.271833
dein	240	0.233135	0.0475611	0.1761485	0.397078
inde	240	0.2137826	0.0396836	0.1633558	0.360707
hum	240	0.2970276	0.252752	0.0909389	1.698113
isu	240	0.206254	0.097225	0.004847	0.396795
innov	240	0.0325321	0.0402828	0.000634	0.1655274
gfi	240	0.254992	0.103459	0.118807	0.643011
fdi	240	0.018826	0.014442	0.000103	0.079594
fina	240	0.3517553	0.2482792	0.01	1

As shown in Table 3, the information suggests that the average value of RGED across regions is 0.337, with a standard deviation of 0.226, which indicates that the total level of RGED is relatively low. Moreover, there are considerable distinctions amongst areas. The average worth of electronic economic climate advancement is 0.628, and the standard deviation is 0.105, indicating a high total degree of digital economy development. The data indicate significant regional variation in human capital levels (Mean = 0.297, SD = 0.253), with a generally low overall level. Similarly, the data show that although the degree of industrial structure upgrading among regions is relatively close, gaps remain that must be addressed (Mean = 0.206, SD = 0.097).

4. Analysis of spatial and temporal evolution characteristics

4.1. Analysis of time evolution characteristics

As can be seen from Figure 4, the development level of China's digital economy has been rising steadily from 2013 to 2020. During the sample period, the average value of China's digital economy development level is 0.628, which indicates that the development of the digital economy is increasingly becoming a crucial driving force for China's economic development.

Figure 5 shows that China's RGED level has generally risen from 2013 to 2020, indicating that the digital economy's development has enhanced RGED to some extent.

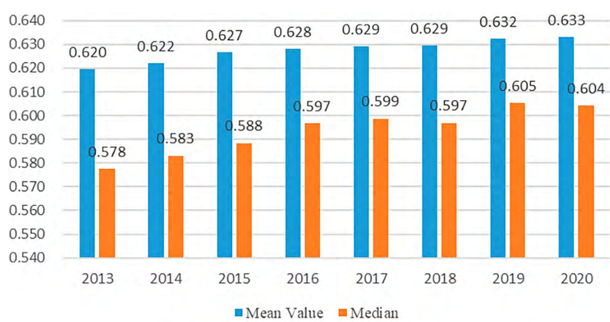


Figure 4. Level of digital economy development in China from 2013 to 2020

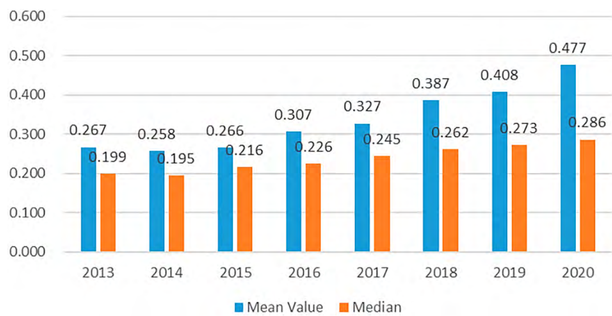


Figure 5. Level of RGED in China from 2013 to 2020

4.2. Analysis of spatial evolution characteristics

As indicated in Figure 6, in terms of various districts, Guangdong, Beijing, Jiangsu, Zhejiang, Shandong, and Shanghai take the lead in electronic economic situation advancement, comprising the "initial rate" of China's digital economic situation growth. Sichuan, Henan, Anhui, Hubei, Fujian, Hunan, Hebei, Shaanxi, Liaoning, and Chongqing remain in the "2nd rate" of China's electronic economy. They have durable advancement energy and fantastic development possibility. Jiangxi, Yunnan, Guangxi, Guizhou, Tianjin, Shanxi, Inner Mongolia, and Heilongjiang come from the "third tier," where the digital economic climate establishes fairly slowly. Jilin, Gansu, Xinjiang, Hainan, Ningxia, and Qinghai lag in digital economy growth and ranking at the end of China's digital economy development level.

Figure 6 indicates that the digital economy development level in 2020 is much greater in the top three rankings of Guangdong (0.951), Beijing (0.816), and Jiangsu (0.811) than in the bottom three rankings of Hainan (0.536), Ningxia (0.528), and Qinghai (0.524). This discrepancy reflects that the ladder distribution characteristic of China's digital economy development is prominent, highlighting the unevenness of China's digital economy development in terms of spatial characteristics.

Figure 7 shows that in terms of provinces, the RGED levels of Beijing, Tianjin, Liaoning, Shanghai, and Hainan are at the forefront of the country, constituting the "first echelon" of RGED in China. RGED in Guangdong, Jiangsu, and Shandong have strong momentum and good development potential and are in the "second echelon" of RGED in China. Zhejiang, Qinghai, Ningxia, Henan, Jilin, and Inner Mongolia are in the "third echelon," and RGED is relatively slow. Heilongjiang, Hunan, Hebei, Chongqing, Gansu, Shanxi, Fujian, Hubei, Sichuan, and Jiangxi lag and are in China's "fourth tier" of RGED. Xinjiang, Shaanxi, Guangxi, Anhui, Guizhou, and Yunnan RGED lag significantly and are at the bottom of China's RGED.

Figure 7 shows that the RGED level of China in 2020 is much greater in the top 5 ranked regions, Beijing (1.000), Tianjin (1.000), Liaoning (1.000), Shanghai (1.000), and Hainan (1.000) than in the bottom five ranked regions, Shaanxi (0.198), Guangxi (0.193), Anhui (0.179), Guizhou (0.157) and Yunnan (0.151). This finding reflects that the ladder distribution of RGED in China is also pronounced, highlighting the severe imbalance in spatial characteristics of RGED in China.

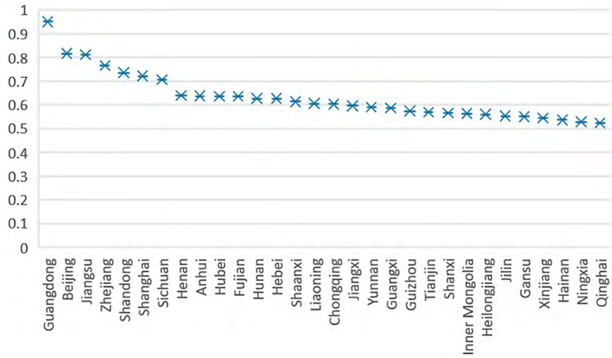


Figure 6. The evolution trend of differences in the level of digital economy development among different provinces in China in 2020

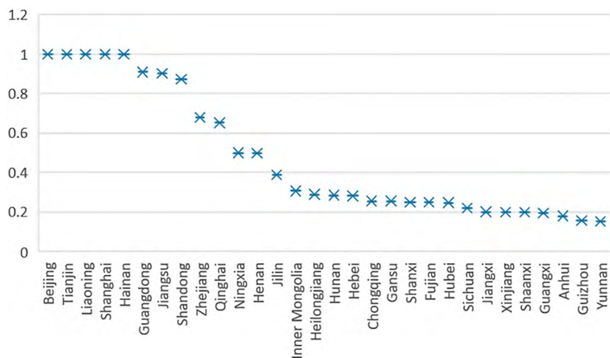
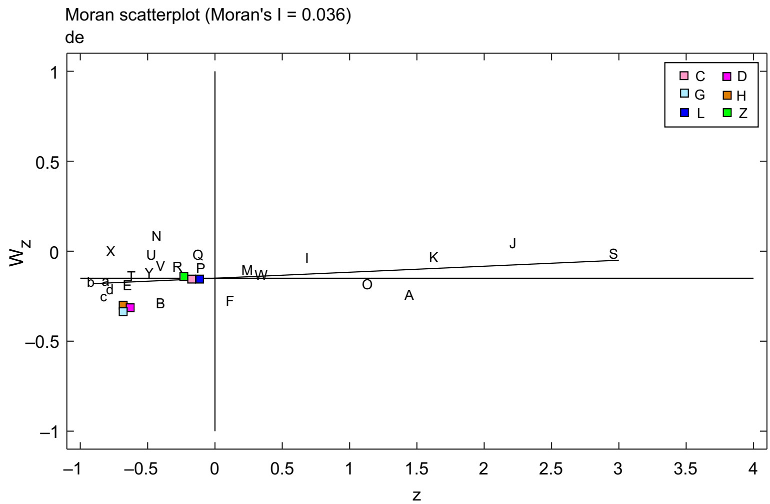


Figure 7. The evolution trend of differences in the level of RGED among different provinces in China in 2020

4.3. Spatial agglomeration analysis

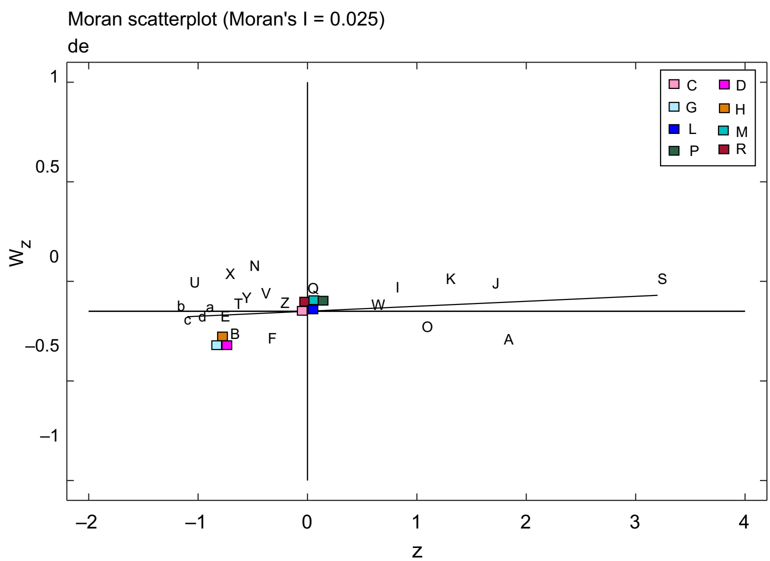
This article makes use of Moran's scatter story to check out the spatial heap of China's electronic economic situation advancement. Stata16.0 software program is made use of to develop local Moran scatter stories. Figures 8–9 reveal the neighborhood Moran scatter stories of the development level of digital economic situation in various districts of China in 2013 and 2020, specifically. There are four quadrants in the Moran scatter plot, with the initial and 3rd quadrants showing favorable spatial correlation. The first quadrant is the H–H type, indicating the load of top-level areas with top-level locations, and the third quadrant is the L–L type, suggesting the agglomeration of low-level locations with low-level areas. Quadrant 2 and Quadrant 4 are unfavorable spatial relationships, with Quadrant 2 being of the L–H type, indicating jumble of low-level areas with top-level locations, and Quadrant 4 being of the H–L kind, indicating pile of high-level locations with low-level locations.

As Figures 8–9 illustrate, the scatter circulation of most of districts lies in the very first and third quadrants, recommending a positive spatial relationship. Districts with innovative digital economy development display stronger connections with other top-level provinces, while those with lower degrees of development show stronger connections with other low-level provinces. Figures 8–9 also indicate that in numerous provinces, the distributed distribution



Note: The letters in Figure 8 correspond to the provinces in parentheses. Specifically, A (Beijing), B (Tianjin), C (Hebei), D (Shanxi), E (Inner Mongolia), F (Liaoning), G (Jilin), H (Heilongjiang), I (Shanghai), J (Jiangsu), K (Zhejiang), L (Anhui), M (Fujian), N (Jiangxi), O (Shandong), P (Henan), Q (Hubei), R (Hunan), S (Guangdong), T (Guangxi), U (Hainan), V (Chongqing), W (Sichuan), X (Guizhou), Y (Yunnan), Z (Shaanxi), a (Gansu), b (Qinghai), c (Ningxia), d (Xinjiang).

Figure 8. Moran scatterplot of digital development in 2013



Note: The letters in Figure 9 correspond to the provinces in parentheses. Specifically, A (Beijing), B (Tianjin), C (Hebei), D (Shanxi), E (Inner Mongolia), F (Liaoning), G (Jilin), H (Heilongjiang), I (Shanghai), J (Jiangsu), K (Zhejiang), L (Anhui), M (Fujian), N (Jiangxi), O (Shandong), P (Henan), Q (Hubei), R (Hunan), S (Guangdong), T (Guangxi), U (Hainan), V (Chongqing), W (Sichuan), X (Guizhou), Y (Yunnan), Z (Shaanxi), a (Gansu), b (Qinghai), c (Ningxia), d (Xinjiang).

Figure 9. Moran scatterplot of digital development in 2020

of digital economic climate growth is in the second and fourth quadrants. This exploration recommends that the development of China's digital economic situation has significant local distinctions, which are very closely pertaining to the various financial frameworks, element endowments, and geographical problems of each province.

5. Analysis of empirical test results

Two regression models (the mixed regression and the fixed-effect models) were screened using an F test to avoid potential heteroscedasticity problems and serial correlation in the panel data. The results show that the mixed regression model was excluded. A Hausman test was performed to compare the fixed-effect and random effects models, leading to the exclusion of the random effects model. The results of the regression analysis are displayed in Tables 4–5.

5.1. Analysis of benchmark regression results

Table 4 illustrates the impact of electronic economic growth on RGED. In Table 4, Column (1) discovers the relationship between the total digital financial development level and RGED. The searching for reveal that there is an impressive "∩– formed" relationship in between the general digital economic advancement level and the RGED level, validating theory H1. The substantial application of electronic innovation has advertised the progression of complete variable productivity, stimulated the electronic makeover of business, made possible the electronic construction of commercial collections, and brought about the institutional development of the financial system. Digital innovation has actually likewise facilitated green innovation by guaranteeing effective resource allotment; however, the increased growth of electronic technology has actually produced several difficulties, consisting of data protection and reduced administration performance, which negatively influenced RGED. The outcomes mentioned above verify Solomon and van Klyton's viewpoint on the connection between the digital economic climate and high-quality financial advancement (Solomon & van Klyton, 2020). Additionally, they are very regular with Olczyk and Kuc-Czarnecka's sight that "digitalization is an essential step of economic growth" (Olczyk & Kuc-Czarnecka, 2022).

Column (2) of Table 4 reveals a noteworthy "U-shaped" connection in between digital facilities and RGED. The first-order and quadratic terms are significant at the 5% level, confirming hypothesis H1a recommended in this paper. The upfront investment in electronic infrastructure is costly, presenting much more strict needs on the building of regional facilities. Notably, the very early-stage digital facilities in underdeveloped regions fails to satisfy the requirements of RGED. A well-developed digital framework is capable of improving the efficiency of production elements, creating knowledge spillover effects, and facilitating the sharing and adaptation of green knowledge among innovative entities, hence driving the growth of RGED. Chen et al. (2023b) argued, "the penetration of digital technologies boosts the modernization of economic infrastructure due to the providing of proactive innovation policy," which is consistent with this paper's view that "digital economic infrastructure is ultimately conducive to green and high-quality development of the economy."

Table 4. Benchmark regression results

	(1)	(2)	(3)	(4)
	ghd	*ghd*	*ghd*	*ghd*
de	11.49^{*}			
	(1.73)			
de^2	-10.72^{**}			
	(–2.27)			
debas		-21.13^{**}		
		(–2.51)		
debas^2		59.38^{**}		
		(2.74)		
dein			-12.27^{***}	
			(–5.79)	
dein^2			31.20^{***}	
			(8.38)	
inde				8.923^{***}
				(2.93)
inde^2				-20.97^{***}
				(–3.09)
innov	–0.402	0.851	0.601	–2.474
	(–0.14)	(0.78)	(0.39)	(–0.58)
gfi	0.809	0.871^{***}	0.803^{***}	0.637
	(1.65)	(4.19)	(4.07)	(1.20)
fdi	-3.826^{***}	2.588	1.928	-3.522^{**}
	(–2.96)	(1.17)	(0.97)	(–2.63)
fina	–0.510	0.315^{*}	0.362^{*}	–0.592
	(–1.09)	(1.71)	(1.75)	(–1.09)
_cons	–2.476	1.767^{**}	0.773	–0.386
	(–1.00)	(2.29)	(1.31)	(–1.46)
N	240	240	240	240

Note: t statistics in parentheses; $^{*}p < 0.1$, $^{**}p < 0.05$, $^{***}p < 0.01$.

Table's 4 Column (3) indicates an obvious "U-shaped" correlation between digital industrialization and RGED. The first-order and quadratic terms are both significant at the 1% significance level, validating hypothesis H1b. Traditional enterprises must overcome technical barriers to achieve technological upgrading when facing the practical application of high-tech, such as digital technology. The release of dividends brought by the improvement of digital technology can drive regional technological progress, accelerate the advancement of traditional industries to mid-to-high-end industries, and then drive RGED. Chen et al. (2023b) found that "initially, enhancing the digital economy's development level may cause a drop in regional total factor productivity, but once the digital economy reaches a certain stage, total factor productivity will rise accordingly," which is consistent with this paper's findings.

Column (4) of Table 4 reveals that industrial digitization and RGED have a significant "∩-shaped" relationship. Both the first-order and quadratic terms show significance at the 1% level, which supports hypothesis H1c. As the extent of the application of regional digital technology, upstream and downstream enterprises in the industrial chain can leverage digital technology achievements more effectively, efficiently integrate low-cost green innovation resources in the region, and realize industrial transformation and upgrading; however, excessive digital applications will bring the inhibitory effect of "information overload." Zhang et al. (2023) contend that industrial eco-efficiency (IEE) is a fundamental requirement in the quest for green, low-carbon, and high-quality development, and their findings reveal that "the temporal correlation between IEE and the digital economy exhibited an inverted V-shape pattern." This finding is consistent with this paper's conclusion that "industrial digitization and RGED have a significant '∩-shaped' relationship."

5.2. Analysis of regression results of mediating effect

This study used a mediating result model with human capital and commercial framework updating considered as mediating aspects to assess the effect of electronic financial growth on RGED. The regression outcomes exist in Table 5.

Table 5. Regression results of mediating effect

	(1)	(2)	(3)	(4)
	hum	*ghd*	*isu*	*ghd*
de	0.938*	1.346***	1.809**	0.727*
	(1.93)	(3.12)	(2.53)	(1.88)
hum		0.254***		
		(3.26)		
isu				0.551***
				(4.22)
innov	1.087	–0.953	1.195	0.845
	(0.67)	(–0.84)	(0.73)	(0.83)
gfi	0.309	0.826***	0.966***	0.924***
	(1.14)	(4.90)	(4.19)	(5.86)
fdi	–2.627***	1.850*	–1.994**	1.689*
	(-3.11)	(1.84)	(–2.47)	(1.70)
fina	–0.339*	0.0737	–0.131	0.329***
	(–1.87)	(0.72)	(–0.77)	(3.92)
_cons	–0.237	–0.823***	–1.131**	–0.644***
	(–0.77)	(–3.19)	(–2.29)	(–2.66)
N	240	240	240	240

Note: *t* statistics in parentheses; *$p < 0.1$, **$p < 0.05$, *** $p < 0.01$.

Table 5 demonstrates that the mediating effect model shows a significant positive influence of digital economic development on human capital at a 10% significance level. This suggests that the electronic economic situation contributes to the improvement of human capital high quality. Additionally, both human capital and digital financial growth have favorable impact coefficients on RGED, symbolizing that the digital economy indirectly promotes RGED by spurring the improvement of human capital. With various other factors held continuous, a one-system boost in electronic financial growth causes a direct rise of 1.346 units in RGED and an indirect boost of 0.238 systems through an equivalent 0.938 – device development in human funding. The total impact amounts to the amount of the direct and indirect results. The total effect amounts to 1.584 systems, with the indirect impact composing 15%. Hence, hypothesis H2 is confirmed. Digital-proficient employees are crucial for the growth of the digital economic climate. Enhancing the top quality of electronic – competent employees can surmount the technological challenges to eco-friendly technology and advancement, increase labor productivity, and indirectly drive the growth of RGED.

As Table 5 shows, when commercial structure updating is regarded as a moderating variable, electronic economic situation has a dramatically positive influence on commercial framework upgrading at a 5% significance level. This indicates that the growth of the electronic economic climate effectively promotes the optimization of the industrial structure. The truth that both commercial structure updating and digital financial development have positive coefficient influence on RGED reveals that the digital economy raises the level of RGED by means of commercial structure upgrading.

With other influencing variables held consistent, a one-unit increase in electronic economic growth causes a 0.727 – system growth in RGED. Furthermore, the influence of industrial framework upgrading on RGED brings about an increment of 0.997 devices. The general impact amounts to 1.724 units, and the indirect effect accounts for 57.8%. The considerable application of electronic modern technology has advertised the improvement and enhancement of typical markets, causing much better resource appropriation, higher technical performance, and greater scale performance. Furthermore, it can reduce carbon emissions, which is beneficial to RGED. Li and Zhao (2023) suggested that the growth of the digital economic situation is essential in speeding up industrial restructuring, maximizing the commercial structure, improving restructuring effectiveness, and promoting industrial upgrades. All these aspects are important motorists for the high-quality growth of local economic situations. Hence, it additionally verifies the research study final thought of this paper: "The updating of the commercial structure serves as an arbitrator in the impact of digital economic advancement on local eco-friendly and high-quality financial development."

5.3. Robustness test

To address the endogeneity issue, 3 approaches are used. Firstly, we designated the lag period of electronic economic advancement as the core explanatory variable. In theory speaking, if the formerly identified equivalent relationship exists between the lag duration of digital financial growth and the existing – duration RGED, the results are reliable. The regression outcomes are presented in Table 6. In the examination, the regression results likewise reveal that there is a considerable "∩-formed" partnership between the overall level of electronic financial growth and the level of RGED. The relationship between digital infrastructure and RGED also reveals a notable "U-shaped" relationship. Column (3) of Table 6 also reveals a significant "U-shaped" relationship between digital industrialization and RGED, and column (4) of Table 6 also reveals that industrial digitization and RGED have a significant "∩-shaped" relationship. Therefore, the above regression results were consistent with previous results, verifying that this study's conclusions are robust.

Table 6. The results of robustness test when the lag period of variables as a core explanatory variable

	(1) the lag period of de as a core explanatory variable	(2) the lag period of debas as a core explanatory variable	(3) the lag period of dein as a core explanatory variable	(4) the lag period of inde as a core explanatory variable
	ghd	*ghd*	*ghd*	*ghd*
de	3.903***			
	(3.08)			
de^2	–4.454**			
	(–2.41)			
debas		–22.02***		
		(–2.82)		
debas^2		60.78***		
		(3.05)		
dein			–10.27**	
			(–3.03)	
dein^2			28.52***	
			(5.02)	
inde				–9.177**
				(–2.68)
inde^2				23.81**
				(3.34)
innov	–0.840	1.163	–4.364***	0.310
	(–0.73)	(1.08)	(–3.82)	(0.96)
gfi	0.810***	0.778***	1.054***	0.808***
	(4.35)	(3.50)	(5.08)	(6.12)
fdi	2.510**	2.446	5.743***	4.092***
	(2.25)	(0.97)	(4.32)	(4.90)
fina	0.386***	0.325	0.486***	0.277**
	(4.00)	(1.69)	(5.86)	(2.69)
_cons	1.200*	1.904**	0.712	0.801*
	(1.77)	(2.64)	(1.33)	(1.95)
N	210	210	210	210

Note: *t* statistics in parentheses; **p* < 0.1, ***p* < 0.05, *** *p* < 0.01.

Second, we added two control variables into the measuring model for the robustness test. Incorporating openness (*open*, assessed by the ratio of total import and export trade to GDP) and fixed asset investment (*invest*, evaluated by the ratio of fixed asset investment to GDP) into the measurement model for control purposes. Minor changes in regression results indicate robustness in the conclusions we made. Table 7 presents the robustness test results when added the two control variables.

Table 7. The results of robustness test when added two control variables

	(1)	(2)	(3)	(4)
	ghd	*ghd*	*ghd*	*ghd*
de	14.49***			
	(2.96)			
de^2	–13.02***			
	(–4.21)			
debas		–21.85***		
		(–4.18)		
debas^2		61.49***		
		(4.53)		
dein			–6.352**	
			(–2.44)	
dein^2			13.68***	
			(2.81)	
inde				6.910**
				(2.24)
inde^2				–16.21**
				(–2.58)
innov	–0.793	0.284	0.331	–2.333
	(–0.35)	(0.45)	(0.39)	(–1.35)
gfi	0.932*	0.989***	0.937***	0.859**
	(1.74)	(6.20)	(5.71)	(2.27)
fdi	–3.024**	2.387**	1.705*	–3.045***
	(–2.48)	(2.50)	(1.80)	(–2.85)
fina	–0.309	0.171	0.225*	–0.346
	(–0.78)	(1.59)	(1.90)	(–1.61)
open	–0.638***	–0.0417	–0.0580	–0.452***
	(–3.89)	(–0.42)	(–0.56)	(–3.62)
invest	–0.148	–0.379***	–0.362***	–0.189***
	(–1.65)	(–6.33)	(–5.85)	(–2.93)
_cons	–3.251	2.191***	0.995***	–0.0683
	(–1.62)	(4.21)	(2.77)	(–0.17)
N	240	240	240	240

Note: *t* statistics in parentheses; *$p < 0.1$, **$p < 0.05$, *** $p < 0.01$.

Furthermore, we conducted variable substitution to conduct a robustness test. Industrial structure supererogation can be used as a substitute for the industrial structure upgrading index. The Equation is expressed as:

$$isah_{it} = \sum_{n=1}^{3} \frac{Y_{int}}{Y_{it}} \times \frac{Y_{int}}{L_{int}},\ n=1,2,3, \tag{6}$$

where the variable $isah_{it}$ represents the degree of industrial structure supererogation for region i in year t. The term Y_{int} indicates the value added by industry n in region i during year t, while Y_{it} is the GDP of region i in the same year. The variable L_{int} refers to the number of employees in industry n of region i in year t, and $\frac{Y_{int}}{L_{int}}$ is the labor productivity of industry n in region i during year t. A higher value signifies a more significant extent of industrial structure supererogation.

After substituting variables, we found a minor difference between the overall test outcomes of the influence of the digital economy on RGED and the benchmark regression outcomes, demonstrating the soundness of the conclusions drawn in this study. The results are shown in Table 8.

Table 8. Regression results of variable substitution

	(1)	(2)
	isah	*ghd*
de	34.74***	0.970**
	(2.96)	(2.49)
isah		0.0151***
		(4.30)
innov	23.94	0.0600
	(0.78)	(0.06)
gfi	8.123	0.975***
	(1.22)	(6.24)
fdi	–77.20***	2.976***
	(–4.07)	(2.94)
fina	–9.583***	0.0505
	(–2.71)	(0.52)
_cons	–6.943	–0.791***
	(–0.91)	(–3.21)
N	240	240

5.4. Heterogeneity analysis

To render the conversation much more comprehensive, we performed a heterogeneity evaluation. We separated our examples right into three separate groups: the eastern area, the central area, and the western area. The regression outcomes exist in Tables 9–11.

As shown in Column (1) of Table 9, there is a considerable "∩-formed" relationship in between electronic economic development and the RGED degree in the eastern area, which remains in line with the previous regression searching for. Nevertheless, Column (1) of Tables 10–11 violates the regression results provided in Table 9. These results recommend that there is a significant "U-shaped" relationship between digital financial growth and RGED in the central and western regions. Column (2) of Tables 9–11 suggests a significant "U-shaped"

Table 9. The results of heterogeneity analysis (eastern region)

	(1)	(2)	(3)	(4)
	ghd	*ghd*	*ghd*	*ghd*
de	11.62*			
	(1.90)			
de2	–11.91***			
	(–3.26)			
debas		–17.55**		
		(–2.00)		
debas^2		41.59**		
		(2.10)		
dein			–11.87*	
			(–1.87)	
dein^2			14.92*	
			(1.67)	
inde				11.30**
				(1.96)
inde^2				–19.77*
				(–1.95)
innov	–0.176	1.979***	–1.936	0.0303
	(–0.08)	(3.17)	(–0.88)	(0.02)
gfi	2.464*	1.611***	–0.0429	1.129*
	(1.92)	(3.12)	(–0.05)	(1.69)
fdi	–2.750*	–0.823	0.0997	–0.180
	(–2.16)	(–0.56)	(0.07)	(–0.13)
fina	–1.552**	–0.188	–0.972**	–0.413*
	(–2.39)	(–1.58)	(–2.07)	(–1.87)
open	–0.683***	–0.113	–0.110	0.0955
	(–4.58)	(–0.79)	(–0.54)	(0.59)
invest	–0.226	–0.540***	–0.00359	–0.426***
	(–1.23)	(–3.45)	(–0.02)	(–3.27)
_cons	–0.532	2.291**	3.169***	–0.944
	(–0.20)	(2.19)	(3.12)	(–1.19)
N	88	88	88	88

Note: *t* statistics in parentheses; *$p < 0.1$, **$p < 0.05$, *** $p < 0.01$.

relationship between digital infrastructure and the level of RGED in all three regions. Column (3) of Table 9 and Table 11 reveals a significant "U-shaped" relationship between digital industrialization and RGED in eastern and western regions, however, this significant relationship was not found in the central region. Column (4) of Tables 9–11 indicates a significant "∩-shaped" relationship between industrial digitalization and RGED in all three regions.

Table 10. The results of heterogeneity analysis (central region)

	(1)	(2)	(3)	(4)
	ghd	*ghd*	*ghd*	*ghd*
de	–41.77***			
	(–2.75)			
de2	33.48**			
	(2.67)			
debas		–39.06***		
		(–4.24)		
debas^2		104.0***		
		(3.98)		
dein			16.81	
			(1.07)	
dein^2			–35.26	
			(–1.20)	
inde				6.426*
				(1.94)
inde^2				–16.74*
				(–1.95)
innov	–3.604**	–0.846	–2.798	0.273
	(–2.09)	(–0.53)	(–1.03)	(0.29)
gfi	0.493	0.783*	0.663	0.116
	(1.17)	(1.92)	(1.87)	(0.60)
fdi	0.854	0.604	0.118	–2.368**
	(0.57)	(0.45)	(0.07)	(–2.21)
fina	0.220	0.198	0.329	–0.0647
	(1.28)	(1.27)	(1.13)	(–0.64)
open	0.0580	0.337	0.257	0.273
	(0.17)	(1.07)	(1.18)	(0.62)
invest	–0.0751	–0.0653	–0.0600	0.00774
	(–1.65)	(–1.53)	(–1.35)	(0.10)
_cons	13.04***	3.569***	–1.930	–0.391
	(2.84)	(4.44)	(–0.96)	(–1.14)
N	64	64	64	64

Note: *t* statistics in parentheses; *p < 0.1, **p < 0.05, *** p < 0.01.

Table 11. The results of heterogeneity analysis (western region)

	(1)	(2)	(3)	(4)
	ghd	*ghd*	*ghd*	*ghd*
de	–6.503**			
	(–2.09)			
de2	5.534**			
	(2.12)			
debas		–22.39***		
		(–4.09)		
debas²		51.76***		
		(3.72)		
dein			–11.63**	
			(–2.37)	
dein²			19.38**	
			(2.45)	
inde				8.867*
				(1.68)
inde²				–21.63*
				(–1.67)
innov	1.054	2.895**	–0.601	0.147
	(0.45)	(2.15)	(–0.25)	(0.08)
gfi	0.413***	0.519***	0.328**	0.687**
	(2.80)	(3.93)	(2.30)	(2.51)
fdi	0.515	0.706	0.00113	–0.660
	(0.57)	(0.69)	(0.00)	(–1.03)
fina	–0.0471	0.0385	0.00341	0.0968
	(–0.59)	(0.36)	(0.04)	(1.14)
open	–0.0740	–0.0490	0.00423	–0.0723
	(–0.63)	(–0.43)	(0.04)	(–0.45)
invest	–0.0768***	–0.0616**	–0.0692***	–0.0728*
	(–2.98)	(–2.07)	(–2.77)	(–1.84)
_cons	2.083**	2.340***	1.723**	–0.827
	(2.20)	(4.38)	(2.55)	(–1.35)
N	88	88	88	88

Note: *t* statistics in parentheses; *$p < 0.1$, **$p < 0.05$, *** $p < 0.01$.

6. Conclusions

In this paper, an examination index framework for digital economy advancement is constructed, and the entropy-weight TOPSIS technique is utilized to determine the improvement of digital financial growth. Additionally, a taken care of – result design is utilized to empirically investigate the impacts of electronic economic growth and its 3 parts, specifically electronic framework, digital industrialization, and commercial digitization, on RGED. The empirical outcomes are as follows.

First, the link between the electronic economy and RGED is non-linear. Particularly, the general level of digital economic development and commercial digitization apply an impressive "∩-designed" influence on RGED, recommending that the influence originally promotes RGED and consequently prevents it. These conclusions are unique compared with the previous ones. We hold that the major reasons are as adheres to. Owing to the considerable application of digital innovation, the digital economic situation has had a substantial effect on the effectiveness of resource allotment and overall performance. Additionally, the electronic economic situation has indirectly innovative RGED by refining and improving the economic or commercial framework; yet, its advertising function might be diminished by particular elements accompanying its modern development. These factors contain the dependancy effect of digital technology and the possible monopoly within the electronic economic climate. Moreover, the fast development of digital innovation causes obstacles such as information security concerns and ineffective administration, which likewise have an impact on RGED.

Second, electronic framework and industrialization significantly impact RGED, which adheres to a "U-shaped" pattern. This conclusion is discussed as follows. There is a high demand for digital facilities during the initial phases of the electronic economic climate, leading to a severe imbalance in digital facilities construction in between financially created and underdeveloped areas, impeding RGED to some extent. Nonetheless, the growth of electronic infrastructure stimulated by the growth of the electronic economic situation can potentially boost performance in various sectors. The industrial framework will certainly continue to optimize and update, better advertising the advancement of RGED.

Third, the electronic economic climate indirectly advertises RGED by affecting the industrial framework and enhancing human capital. The indirect effect of the human funding level on the digital economic situation and RGED represent 15%, suggesting that enhancing the literacy of digital-skilled workers will certainly surmount the technical challenges to eco-friendly development and development, and thus indirectly drive the advancement of RGED. Furthermore, the indirect impact of commercial framework upgrading on RGED through the electronic economic situation totals up to 57.8%. This indicates that the comprehensive application of electronic modern technologies has advertised the makeover and enhancement of traditional markets. This situation can enhance source allowance performance, technological performance, and range efficiency, in addition to reduction environmental pollutant emissions, benefiting RGED.

7. Implications

Based upon the research results we acquired, we put forward the following practical ideas to enhance environment-friendly modern technology advancement, drive high-quality economic growth, and aid relevant economies in developing plans to sustain RGED.

First, governments and relevant authorities should upgrade the digital infrastructure. The analysis indicates a "U-shaped" correlation between RGED and digital infrastructure, suggesting an impact of first inhibition and then promotion, which has a particular relationship with the large initial investment and high digital infrastructure requirements. Therefore, expediting the progress of digital infrastructure construction, increasing investment in this domain, and promoting digital infrastructure to improve RGED are essential for reaching the development inflection point at the earliest opportunity. Managers can accelerate the progress of information network infrastructure construction, especially in underdeveloped areas, including the construction of gigabit optical fiber networks and 5G network infrastructure. Moreover, relevant departments can promote the intelligent upgrade of infrastructure in an orderly manner and build intelligent and efficient integrated infrastructure. Investing in artificial intelligence infrastructure aids in strengthening the ability to empower intelligent industries.

Second, governments and relevant departments should expedite the process of digital industrialization. We found a significant "U-shaped" correlation between digital industrialization and RGED, indicating that the current pace of digital transformation is low and may struggle to fulfill the demands of RGED. Therefore, it is necessary to overcome digital technical barriers more quickly to realize technology upgrading, release digital technology dividends as soon as possible, drive regional technological progress, and drive RGED through digital industrialization. Establishing a digital innovation fund is proposed to support cutting-edge technological research and development by startups, accelerating the commercialization of technologies. Creating a digital industrial ecosystem is suggested to facilitate collaboration between large enterprises and startups, promoting innovative applications of digital technology across various industries. Additionally, initiating talent training programs in the digital field, focusing on nurturing professionals with a background in the digital economy, is recommended to meet the talent demands of digital industrialization. Managers should concentrate on strategic cutting-edge areas, enhancing the foundational research and development (R&D) capabilities of digital technologies. Furthermore, it is advisable to promote collaborative innovation among firms within this sector, platform-based firms, and enterprises specializing in digital technologies. These firms can cultivate a multifaceted innovation ecosystem that advances the intelligent economy through the integration of digital technologies, smart products, and optimized service operations.

Third, governments should vigorously promote digitalizing traditional industries, enabling their transformation. Integrating digital technologies and traditional industries is essential for developing the digital economy, and industrial digitalization represents a fundamental aspect of this process. The study suggests that industrial digitization and RGED have a significant "∩-shaped" relationship, showing the influence effect of the promotion first and then inhibition, indicating that the earlier the promotion of industrial digital transformation, the more conducive to RGED. It is recommended to expedite the digital transformation of businesses by digitizing R&D, production, processing, management, sales, and service operations, etc. Furthermore, incorporating virtual reality and augmented reality technologies should be proposed to elevate the digitalization levels of traditional industrial production lines, optimizing processes and quality control. It is suggested to present benefit systems for digital change to urge typical industrial business to welcome advanced digital technologies like industrial IoT and big data evaluation, so as to boost performance and cut down expenses. Establishing digital entrepreneurship platforms encourages collaboration between digital technology enterprises and traditional industrial counterparts in exploring innovative digital solutions.

Managers should intensify digital efforts in pivotal sectors. Traditional industries should undergo comprehensive transformation. Service sectors, including commerce, trade, finance, and logistics, should adopt digital transformation to enhance industry integration through digital technologies.

Fourth, the government and managers ought to use the impact of human resources and the updating of commercial framework. Our research study shows that the electronic economy indirectly promotes RGED via moderating variables. Human capital serves as a critical mediator. Individuals can overcome technical barriers to green innovation and development by enhancing digital talent literacy, improving labor productivity, and indirectly promoting RGED. In particular, it is recommended to launch a nationwide campaign to promote digital capacity and skills. In essence, managers should focus on strengthening information technology programs in primary and secondary education, develop more digital technology professionals through vocational colleges, establish modern industrial schools in collaboration with businesses and academic institutions, and collaborate with labs and training facilities to introduce diverse training methods, such as customized programs and modern apprenticeships. Taking the upgrading of the industrial structure as a moderating factor, the comprehensive infiltration of electronic technology right into numerous industrial fields needs to be expedited. Additionally, the assimilation and innovation of digital modern technology and application scenarios, in addition to the improvement of organization models, should be thrust. Managers should aim to cultivate a new development paradigm where technological advancements lead to increased total factor productivity and practical applications drive further technological innovation.

8. Limitations and future research

First, a notable limitation lies in the temporal constraints of the data used, spanning from 2013 to 2020. Unfortunately, for various reasons, data for 2021 to 2023 are unavailable, creating a gap in the analysis for this period. This restraint highlights the need of bewaring when prolonging the findings to a lot more recent years and prompts the purchase of even more current data to guarantee the sturdiness and timeliness of the study's conclusions. Second, the generalizability of the findings is another limitation, given the exclusive focus on China's provincial data. Future research should consider expanding the scope to incorporate diverse regions and countries, ensuring a broader applicability of the observed patterns and relationships. Additionally, external factors like global economic conditions and geopolitical events might still influence the observed relationships while controlled to a certain extent in the study. Accounting for these externalities presents a challenge, and future research could explore the dynamic interplay between these factors and the digital economy's impact on RGED.

First, future research endeavors should prioritize a longitudinal analysis with a continuous dataset extending beyond 2023. With this method, an extra in deepness evaluation of the changing fads and characteristics in the connection in between the electronic economic situation and RGED can be executed. Furthermore, an in-depth sectorial analysis within the digital economy is warranted. Examining specific sectors' contributions and challenges to

RGED would provide targeted insights and facilitate more tailored policy recommendations. Finally, future research should focus on assessing the impact of specific policies, including those recommended in this study, on actual RGED outcomes. This practical approach would enhance our understanding of policy effectiveness and implementation strategies, contributing to more informed decision-making processes.

9. Discussion

This study looks into the complicated connection in between the digital economic climate and RGED, integrating study results from diverse academic point of views. Our research discovers a non-linear, inverted-U-shaped correlation in between the digital economic situation and RGED, which is distinct from previous research. To resolve the oversight of green eco-friendly advancement in previous studies, this paper takes into consideration both economic and eco-friendly benefits when determining RGED, therefore conquering the constraints of a single-dimensional measurement of the electronic economy. In addition, our theoretical model checks out the moderating duties of human resources and commercial framework updating to identify relevant findings for. We find that while the electronic economic climate holds assurance for enhancing local financial development and quality, numerous challenges and limitations need to be resolved.

Additionally, our research underscores the critical nature of mixing sustainable actions and environment-friendly modern technologies within economic approaches, aiming to reach both economic growing and ecological sustainability. While the digital economy has the potential to make substantial payments to regional economic situations, its effect on RGED stays a subject of discussion. We worry the requirement of extra research to illuminate the complex partnership between the electronic economy and RGED, considering aspects like resource efficiency, well balanced growth, and environmental preservation.

In general, our research stresses the detailed connection between the digital economic climate and RGED, supplying beneficial point of views on the chances and challenges developing from the digital economy's growth in the context of regional financial growth and sustainability. By addressing these challenges and seizing the opportunities presented by the electronic economic climate, policymakers and stakeholders can function towards advertising lasting and comprehensive financial development at the regional level.

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Author contributions

LQ and ZW conceived the study and were responsible for the design and development of the data analysis. LQ, ZH and ZW were responsible for data collection and analysis. LQ and ZW were responsible for data interpretation. LQ and ZW wrote the first draft of the article. XH, KZ and ZW revised the manuscript.

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No potential conflict of interest was reported by the authors.

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