Research on the impact of digital economic development level on ecological environment

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Abstract

Purpose – Exploring the intrinsic connection between the ecological environment and the digital economy and empirically testing how the level of digital economic development affects the ecological environment. Using the entropy weighting method to analyze the weights of the indicators in the digital economic development level and ecological environment system to explore the factors that have the greatest impact on the ecological environment in the indicator system of the digital economic development level so as to deepen the theoretical understanding of the relationship between the level of development of the digital economy and the ecological environment. Explore the regional heterogeneity of the level of development of the digital economy to promote the healthy development of China's ecological environment proving the difference in the level of development of the digital economy in the east west and central regions of China and the difference in the effect on the ecological environment.

Design/methodology/approach – Based on the panel data of 30 provinces in China from 2013 to 2021 this paper fits the index system of digital economy development level with three factors. A digital infrastructure digital industry and digital application combines environmental pollution and energy consumption to construct ecological environment indicators and explored the impact of digital economy development level on the ecological environment by using the entropy weight method and the random effect model.

Findings – The findings indicate that the degree of digital economic development has a positive and significant impact on promoting the healthy development of the ecological environment, in which the digital industry has the greatest impact on the ecological environment. Meanwhile, the improvement of industrial structure also has a positive effect on the improvement of the ecological environment, whereas the level of human capital inhibits the healthy development of the ecological environment, and the governmental support fails to effectively and significantly promote the improvement of the ecological environment. Furthermore, the empirical research indicates that the level of digital economy development has obvious regional heterogeneity on the healthy development of the ecological environment: the eastern and central regions have a significant effect, while the western region has a less significant effect.

Originality/value – Although domestic and foreign scholars and experts have conducted sufficient studies on the ecological environment and the development level of digital economy respectively, there are few studies on the empirical analysis of the positive significance and regional heterogeneity of the impact of the development level of digital economy on the ecological environment, which can be supplemented and referred to in this study. At the same time, it also provides intellectual support for our country to achieve high-quality development of digital economy and efficient governance of ecological environment.

Keywords Digital economy, Ecological environment, Entropy weight method, Fixed effect model, Regional heterogeneity

Paper type Research paper

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1. Introduction

In 2022, the scale of China's digital economy will reach 50.2 trillion yuan, accounting for 41.5% of GDP, and the digital economy will gradually become China's main form of economy and a new driving force to drive national economic development (Liu and Yanfei). It is explicitly proposed in the "Fourteenth Five-Year Plan for National Economic and Social Development of the People's Republic of China and Outline of Vision Goals for 2035" that "with the construction of ecological civilization as the overarching principle and digital transformation as the breakthrough, to promote the green and low-carbon transformation of economic and social development." and under the guidance of this strategic goal, the deep integration of the new generation of information technology with the digital economy as the core and the green economy not only achieves resource conservation and environmental friendliness, but also plays a very important role in production and manufacturing, life services, and other aspects. It provides a new development space for realizing the healthy and sustainable development of the ecological environment and promoting the harmonious coexistence of human beings and nature. As a result, in the current wave of scientific and technical revolution and industrial transformation, it is very necessary to investigate the intrinsic logical connection between the level of development of the digital economy and the ecological environment, which provides intellectual support for our country to achieve the high-quality development of the digital economy and the efficient governance of the ecological environment.

At present, the academic research on the level of development of the digital economy and the ecological environment mainly focuses on the following three aspects: First research on measuring the development level of digital economy. Tang *et al.* (2023) established a system of indicators for assessing the development level of China's digital economy in terms of digital infrastructure, digital innovation capacity, digital industry scale, digital technology application, and measured the development level of China's digital economy (Tang *et al.*, 2023). Based on the four dimensions of digital foundation, digital application, digital innovation and digital environment, CAI Cai *et al.* (2022) studied the spatio-temporal evolution characteristics of China's digital economy with the help of entropy weight method, and found that there were significant differences in the development level of China's regional digital economy (Cai *et al.*, 2022). Jijun *et al.* (2022) compiled and evaluated the development level of digital economy in provinces based on four aspects: digital infrastructure, digital industrialization, industrial digitalization and digital innovation potential, and found that there were obvious differences in the development of digital economy in provinces, but such differences showed a decreasing trend (Jijun *et al.*, 2022). Jiao and Sun 2021) constructed a comprehensive evaluation index system of China's inter-provincial digital economy based on four dimensions: digital foundation, digital application, digital innovation, and digital transformation, and then launched a spatial and temporal heterogeneity of China's inter-provincial digital economy development level and their influencing factors in a spatial SAR analysis (Jiao and Sun, 2021). Pan *et al.* (2021) established an evaluation index system for digital economy development from the four aspects of digital economy infrastructure, digital industrialization, industrial digitalization and digital governance, and used the entropy method for evaluation, finding that the development of digital economy showed an obvious ladder distribution among provinces (Pan *et al.*, 2021). Secondly, the comprehensive evaluation of ecological environment quality. Xing *et al.* (2021) analyzed the variation differences of each factor based on the five dimensions of the driving force, pressure, state, influence, and response, and then carried out a comprehensive analysis (Xing *et al.*, 2021). Ren and Lv (2019) established an evaluation index system for ecological environment quality and used the fuzzy comprehensive evaluation method based on AHP to evaluate the ecological environment quality index, and found that the overall ecological environment quality at the national level was gradually improved, and in some areas it showed a fluctuation (Ren and Lv, 2019). Lu (2015) established an ecological environment quality evaluation system based on the PSR framework and used the principal component analysis method for evaluation, and the research results showed that the ecological environment quality at the national level continued to decline (Lu, 2015). Liu and Ren (2007) proposed an ecological environment quality evaluation method based on the grey system theory in combination with the actual situation of Shaanxi Province and applied the method to the region (Liu and Ren, 2007). Thirdly, the promotion effect of the level of development of the digital economy on ecological protection and green development. Based on the urban panel data of 280 prefecture-level cities in China from 2011–2019, Guo and Ma (2022) used component analysis and SBM-Malmquist method to measure the level of development of the digital economy and green total factor productivity in China's major cities, and conducted an empirical analyses on it. The results show that the digital economy has a significant driving effect on urban green total factor productivity, that is, the digital economy can indirectly promote urban green total factor productivity by enhancing green innovation, and industrial structure upgrading (Guo and Ma, 2022). Based on the panel data of 30 provinces in China from 2012 to 2020, Liu (2022) analyzed the enabling effect of digital technology innovation applications on industrial green transformation. The results show that digital technology has an obvious enabling effect on China's industrial green transformation, and its enabling effect has regional heterogeneity (Liu). Ding and Qin (2021) show that ICT can significantly promote the efficiency of green economy, and the promoting effect of ICT on the efficiency of green economy in eastern, central and western regions declines successively (Ding and Qin, 2021). Zhou and He (2020) believe that digital economy can reduce the excessive consumption of tangible resources and energy in traditional industrial production process by promoting the digitalization and intelligent development of economy, thus curbing environmental pollution and ecological deterioration (Zhou and He, 2020). Hagen (2018) proposed that the reform and innovation of the property rights system triggered by the proliferation of the digital economy, which can use the constraints and incentive mechanisms to reduce the manufacturing costs and negative externalities of production, and then protect the ecological resources and natural environment (Hagen, 2018).

Although scholars and experts at home and abroad have conducted sufficient studies on the ecological environment and the development level of digital economy respectively, the research on the relationship between the two is limited to the promotion role of digital technology on green economy, and theoretical research is conducted on the impact of the development level of digital economy on the ecological environment through control variables. And there are few studies on the positive significance and regional heterogeneity of ecological environment influenced by the development level of digital economy. Therefore, the contributions of this paper mainly include: (1) exploring the intrinsic connection between the ecological environment and the digital economy, and empirically testing how the level of digital economic development affects the ecological environment. (2) Using the entropy weighting method to analyze the weights of the indicators in the digital economic development level and ecological environment system, to explore the factors that have the greatest impact on the ecological environment in the indicator system of the digital economic development level, so as to deepen the theoretical understanding of the relationship between the level of development of the digital economy and the ecological environment. (3) Explore the regional heterogeneity of the level of development of the digital economy to promote the healthy development of China's ecological environment, proving the difference in the level of development of the digital economy in the east, west, and central regions of China, and the difference in the effect on the ecological environment.

2. Theoretical mechanisms and research hypotheses

2.1 Effects of the level of development of the digital economy on the ecological environment

Digital economy, as a new economic form with data as production factor, modern information network as the main carrier, integrated application of information and communication technology and digital transformation of production factors as an important driving force (He *et al.*, 2022), its development characteristics of high technology, high growth and high cleanliness have produced significant positive effects on the healthy and sustainable development of ecological environment. This is mainly reflected in the following three aspects: First, the development of digital economy is conducive to energy conservation and emission reduction, and improve the efficiency of resource utilization. The digital economy can provide enterprises with efficient access to market information, thus alleviating the imbalance in the allocation of resources between regions and industries, realizing the effective allocation of resources, and making the input of production factors more concentrated and efficient. At the same time, different from the excessive consumption of resources by traditional industrial production, the new industrial production integrated with the digital economy is more intelligent, lightweight and green, which has a significant effect on reducing resource consumption, reducing pollution emissions, and improving production efficiency. Second, the development of digital economy is conducive to intelligent monitoring, so as to achieve efficient protection of ecological environment quality. Digital technology can accurately measure the cost of environmental pollution, and define the cost borne by enterprises by comprehensively recording the pollution emissions of enterprises in the production process, so as to help enterprises to upgrade production technology, optimize processes, and update equipment to reduce the cost of environmental pollution (Zhu and Pang, 2022). At the same time, the digital platform can not only reduce the cost of information exchange within the industry, but also help enterprises optimize the production service process through real-time monitoring, collection and analysis of energy flow data, so as to reduce the unnecessary loss of energy resources in the production process and timely adjust the production status. Third, the development of digital economy is conducive to industrial upgrading and reducing environmental pollution. With its unique advantages, the digital economy integrates information technology with the manufacturing industry chain and value chain, transforming the production mode from traditional manual control to advanced intelligent control, thus achieving the transformation and upgrading of the industrial structure. Therefore, the industrial transformation and upgrading promoted by the digital economy not only improves the overall output efficiency of the region, but also reduces backward production capacity and pollution emissions, laying a solid foundation for the healthy and sustainable development of the ecological environment.

H1. The digital economy has a positive and significant impact on ecological health.

2.2 The regional heterogeneity of the development level of digital economy on China's ecological environment

Due to the vast territory of our country, the natural conditions, development level and cultural environment of different places are obviously different, in the process of economic and social development, there are significant differences between different regions. Therefore, the impact of the development of the digital economy on different regions is not the same (Shujuan *et al.*, 2022). The heterogeneity of digital effects is mainly reflected in the information foundation, network integration, digital talents and digital technology output, etc., which makes the development level of digital economy show obvious heterogeneity in the spatial distribution of the healthy development of ecological environment. Among them, the eastern region has a deep economic foundation and is generally more attractive to talents and technologies than the central and western regions, which provides a good environment for the development of the digital economy. The improvement of the level of digital economy has a significant role in promoting the agglomeration of production factors, especially innovative factors, and the rapid development of advanced technologies, thus transforming the development of manufacturing industry to technology-intensive, promoting the optimization and upgrading of industrial structure, and comprehensively carrying out intelligent transformation of energy development, transportation and public life facilities, thus promoting the healthy development of ecological environment. Therefore, in the eastern region of our country, the development of digital economy has certain first-mover advantages. Compared with the central and western regions, the scale of digital economy is relatively low, but in recent years, due to the government's support and policy tilt, the development level of its digital economy has been greatly improved, and is developing in the direction of scale economy.

H2. There is significant regional heterogeneity in the impact of the level of development of the digital economy on the development of ecological health.

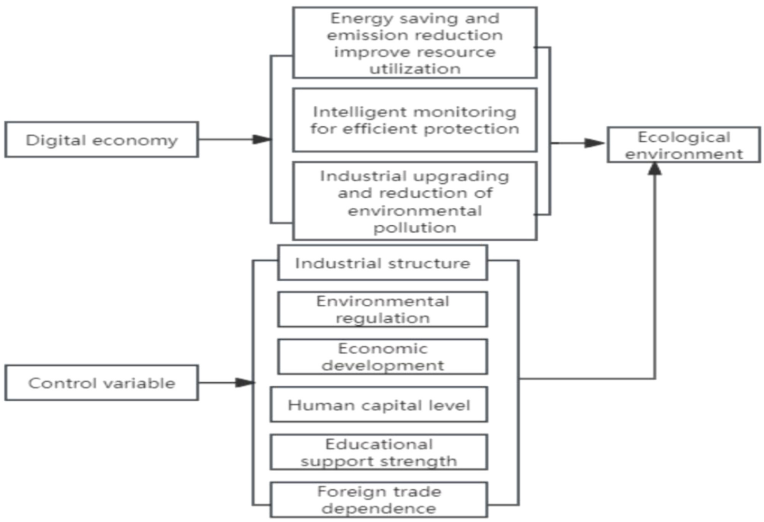
3. Research methods and index selection

3.1 Mechanisms of influence between variables

The digital economy incorporates data as a new factor of production into resource allocation, which has a high green value because of its simplicity and efficiency of development. The digital economy contributes to the healthy development of the ecological environment by improving the efficiency of resource use, real-time intelligent monitoring, and optimizing the upgrading of industrial structures. In addition,Economic development、Industrial structure、Environmental regulation、Educational support strength、Human capital level and Foreign trade dependence also play different roles in promoting the healthy development of the ecological environment. Therefore, the transmission mechanism of the level of digital economy development on the ecological environment is shown in Figure 1.

3.2 Index system design and data source

3.2.1 Explained variables. The explained variable is ecological environment (EE). The ecological environment, as a composite ecosystem covering multiple fields such as resources, economy, environment, and society, must follow certain principles when designing indicator



Source(s): Chart prepared by authors

Figure 1. Transmission mechanism of the level of development of the digital economy on the ecological environment

systems to ensure that the constructed indicator systems are scientific, systematic, and complete. The pressure-state-response framework organizes and classifies ecological indicators, reflecting the interrelation and interaction between human and natural environment. The index system built based on this framework meets the requirements of scientificity, systematicness and integrity. Therefore, based on the pressure-state-response framework and referring to the research of (Ren and Lv, 2019), this paper established an indicator system for ecological environmental quality assessment (as shown in Table 1). Among them, the environmental pressure subsystem reflects the pressure of human social production activities on natural environment from the aspects of population and environment. The environmental status subsystem reflects the current state and situation of ecological environment from the aspects of vegetation cover and per capita green space. The environmental response subsystem reflects the desire to pursue ecological environmental protection and green development through the management and protection measures of ecological environment. At the same time, the entropy method is used to objectively assign weight to the indicators and calculate the comprehensive score, so as to objectively and scientifically evaluate the ecological environment quality level of each region.

3.2.2 Core explanatory variables. The explanatory variable is the digital economy (DE). This article draws on existing research on the evaluation of the digital economy, identifies common indicators, and constructs a digital economy indicator system based on fifteen specific indicators from three dimensions: digital infrastructure, digital industry, and digital environment (as shown in Table 2) (Luo *et al.*, 2022; Wang *et al.*, 2022; Ren, 2020; Yang and

Primary index	Secondary index	Three-level index	unit	Types
Ecological environment	Ecological environment pressure	Population density	Persons/km^2	–
		Intensity of sulfur dioxide emission in exhaust gas	Tons/billion yuan	–
		General industrial solid waste produces strength	Tons/billion yuan	–
		Smoke (dust) emissions per unit of GDP	Tons/billion yuan	–
		Per capita COD emission	kg/person	–
		Natural population growth rate	%	–
	Ecological environment status	Per capita water resources	m3/person	+
		Forest coverage rate	%	+
		Per capita domestic waste removal volume	Tons per person	+
		Per capita urban green space	Hectare per person	+
		Arable land per capita	Hectare per person	+
		Per capita park green space area	Square meter	+
	Ecological Environment response	Green coverage rate of built-up area	%	+
		Afforestation area	Ha	+
		Comprehensive utilization rate of general industrial solid waste	%	+
		Harmless treatment rate of household garbage	%	+
		Completed investment in industrial pollution control	Ten thousand yuan	+
		Sewage treatment rate	%	+

Source(s): Chart prepared by authors

Table 1. Ecological environment evaluation index system

Zhao, 2022; Han *et al.*, 2022; Chen and Jia, 2020). The entropy method is used to objectively weight each indicator. Specifically, (1) Digital infrastructure is the foundation for the sustainable development of the digital economy. That is, the more mobile phones and Internet broadband access means the higher the level of communication and informatization in the region, and the faster the development of digital economy. Based on this, mobile phone users at the end of the year, Internet broadband access users, long-distance optical cable line length, telephone penetration, the number of Internet domain names and IPv4 addresses are selected to reflect the level of regional digital infrastructure. (2) The digital industry is the core of the rapid development of the digital economy. With the development of digital technology, the carrier of the internet is not limited to computers. The Internet is gradually combined with mobile communication technology and applied to practice, which has effectively promoted the rapid development of the digital economy. Based on this, the total number of telecommunications services, digital industry employees, software business income, e-commerce, and the number of enterprises with e-commerce transaction activities are selected to reflect the development level of the digital industry. Among them, the number of digital industry employees is represented by the number of urban unit employees in the information transmission, software, and information technology service industries. (3) As an important lever to promote the development of the digital economy, the digital environment has been vigorously promoted by various countries in the field of digital economy, with a focus on promoting innovation in relevant industrial policies, in order to further optimize the development environment of the digital economy. Based on this, select the Digital Inclusive Finance Index、The transaction volume of the technology market、R&D expenditure and the number of websites owned by enterprises comprehensively reflect the degree of digital environment governance.

3.2.3 Control variables. The healthy development of the ecological environment is influenced by various factors. This article draws on the research of Liu and Yanfei (2023), Chen and Zhang (2021), Zhu and Zhang (2020), Zhang and Zhu (2017), and selects industrial

Table 2.
Digital economy evaluation indicator system

Primary index	Secondary index	Three-level index	unit	Types
Digital economy	Digital infrastructure	Mobile phone year-end users	Wan hu	+
		Internet broadband access users	Wan hu	+
		Length of long distance optical cable line	kilometre	+
		Telephone penetration rate	Department/100 people	+
		Number of Internet domain names	Ten thousand	+
		Number of IPv4 addresses	Ten thousand	+
	Digital industry	Total telecommunications services	Billion	+
		Digital industry practitioners	Thousands of people	+
		Software revenue	Ten thousand	+
		Electronic commerce	Billion	+
		Number of enterprises with e-commerce trading activities	–	+
	Digital environment	Digital Inclusive Finance Index	–	+
		Technology market turnover	Ten thousand	+
		R&D expenditure	Billion	+
		Number of websites owned by the enterprise	–	+

Source(s): Chart prepared by authors structure (IS)、human capital level (HCL)、foreign trade dependence (Ft)、economic development (ED)、environmental regulation (ER) and education support (Edu) as control variables. The industrial structure (IS) refers to the proportion of the added value of the primary industry in GDP, and the improvement of the industrial structure will inevitably lead to changes in land use patterns, thereby affecting the improvement of the ecological environment. The Human Capital Level (HCL) is characterized by the average number of students enrolled in higher education institutions per 100,000 people, with a larger indicator indicating a higher level of human capital. Foreign Trade Dependence (Ft) selects the ratio of the total import and export volume of each region to the regional GDP to measure trade openness. Among them, the total import and export amount is converted based on the average exchange rate of the current year. Economic development (ED) is measured by regional gross domestic product (GDP); Environmental regulation (ER) is measured by the proportion of investment in industrial pollution control to GDP; Education support (Edu) is measured by the proportion of education expenditure to fiscal expenditure.

3.2.4 Data sources. Considering the authenticity and availability of the data, the data samples of this paper are panel data of 30 provinces in China from 2013 to 2021, and all the original data are mainly obtained from China Statistical Yearbook, China Environmental Statistical Yearbook, as well as statistical yearbooks of each province and statistical bulletins of the relevant provinces (municipalities). Individual missing values are corrected by interpolation, and the data of Tibetan provinces with too many missing values during the study period are excluded. In order to eliminate the possible "heteroscedastic" problem, logarithms of variables such as economic development (ED)、foreign trade dependence (Ft) and human capital level (HCL) were first taken, and then fixed effect regression model was introduced and processed by Stata15.0 software.

3.3 Improved entropy weight method

The entropy value method determines the weights of the evaluation results based on the information that each evaluation method can convey, which avoids the subjectivity of the evaluation results as well as the overlapping of information between multiple indicators. Compared with the traditional entropy value method, the improved entropy value method eliminates some extreme or negative values by standardizing the raw data to ensure more accurate measurement results. The specific calculation steps are as follows:

(1) Indicator data standardization. To eliminate the influence of the scale on the data, standardization was carried out by applying the method of change in extreme deviation.

$$\text{Positive indicators: } (1)\, Y_{ij} = \frac{x_{ij} - \min_i\{x_{ij}\}}{\max\{x_{ij}\}_i - \min\{x_{ij}\}} \tag{1}$$

$$\text{Negative indicators: } (2)\, Y_{ij} = \frac{\max_i\{x_{ij}\} - x_{ij}}{\max\{x_{ij}\}_i - \min\{x_{ij}\}} \tag{2}$$

x_{ij} is the initial value of the i-th indicator in the j-th year; Y_{ij} is the standardised value of the i-th indicator in the j-th year; i = 1,2, . . ., m, m is the number of evaluation indicators; j = 1,2, . . ., n, n is the number of evaluation years.

(2) Indicator data normalization. The use of the entropy method to calculate the weights of indicators needs to take logarithms, and there are zeros in the normalized data matrix, so the normalized data matrix will be shifted to the right by one unit to avoid meaninglessness in the calculation.

$$Y_{ij}' = Y_{ij} + 1 \tag{3}$$

(3) Determination of indicator weights w_{ij}

① First calculate the indicator Y_{ij}' weighting of the indicator

$$P_{ij} = \frac{Y_{ij}'}{\sum_{j=1}^{n} Y_{ij}'} \tag{4}$$

② then calculate the information entropy e_i of each index

$$e_i = -\frac{1}{\ln n}\sum_{j=1}^{n} p_{ij} \ln p_{ij} \tag{5}$$

Where ln1 is equal to 0. The redundancy of the differences in the indicators was calculated using $d_i = 1 - e_i$, and then $w_{ij} = \frac{d_{ij}}{\sum_{j=1}^{n} d_{ij}}$ was used to determine each indicator's x_i the weighting of each indicator w_{ij} .

(4) Measurement of the comprehensive evaluation index of the system

$$U_k = \sum_{j=1}^{n} w_{ij} Y_{ij} \tag{6}$$

The weights of the indicators in the evaluation system were calculated using the above method, and the results are shown in Tables 3 and 4.

Analysis of measurement results: As can be seen from Tables 3 and 4, in the index system of ecological environment, the environmental state subsystem has the highest weight, with a comprehensive weight of 0.561, followed by the environmental response subsystem with a comprehensive weight of 0.358, and the environmental pressure subsystem with a comprehensive weight of 0.081. At the same time, per capita water resources is the factor with the greatest weight among all indicators, and the weight

Primary index	Secondary index	Three-level index	Entropy value	Weight
Digital economy	Digital infrastructure	Mobile phone year-end users	0.958	0.036
		Internet broadband access users	0.949	0.043
		Length of long distance optical cable line	0.967	0.028
		Telephone penetration rate	0.974	0.022
		Number of Internet domain names	0.902	0.083
		Number of IPv4 addresses	0.896	0.089
	Digital industry	Total telecommunications services	0.911	0.076
		Digital industry practitioners	0.910	0.077
		Software revenue	0.867	0.113
		Electronic commerce	0.919	0.069
		Number of enterprises with e-commerce trading activities	0.899	0.086
	Digital environment	Digital Inclusive Finance Index	0.976	0.021
		Technology market turnover	0.869	0.111
		R&D expenditure	0.904	0.082
		Number of websites owned by the enterprise	0.924	0.064

Source(s): Chart prepared by authors

Table 3.
Digital economy development level index weight

Primary index	Secondary index	Three-level index	Entropy value	Weight
Ecological environment	Ecological environment pressure	Population density	0.994	0.012
		Intensity of sulfur dioxide emission in exhaust gas	0.996	0.009
		General industrial solid waste produces strength	0.995	0.009
		Smoke (dust) emissions per unit of GDP	0.994	0.013
		Per capita COD emission	0.999	0.002
		Natural population growth rate	0.982	0.036
	Ecological environment status	Per capita water resources	0.921	0.157
		Forest coverage rate	0.965	0.070
		Per capita domestic waste removal volume	0.962	0.076
		Per capita urban green space	0.951	0.099
		Arable land per capita	0.937	0.126
		Per capita park green space area	0.983	0.033
	Ecological Environment response	Green coverage rate of built-up area	0.989	0.022
		Afforestation area	0.950	0.099
		Comprehensive utilization rate of general industrial solid waste	0.975	0.050
		Harmless treatment rate of household garbage	0.997	0.007
		Completed investment in industrial pollution control	0.940	0.120
		Sewage treatment rate	0.970	0.060

Source(s): Chart prepared by authors

Table 4. Ecological environment index weight

is 0.157, indicating that per capita water resources have the greatest impact on the ecological environment. Therefore, in order to improve the quality of the ecological environment, it is necessary to increase the per capita water resources. Therefore, in the process of optimizing the ecological environment, corresponding measures should be taken according to the impact degree of each indicator, so as to effectively improve the healthy development of the ecological environment. In addition, in the index system of digital economy, the weight of software business income is the highest, with a weight of 0.113, indicating that software business income has the greatest impact on the development of digital economy and is the core foundation of digital economy development. Therefore, increasing software business income can bring new development space for digital economy. In addition, in the digital economy evaluation index system, the comprehensive weight of digital industry and digital infrastructure is the highest, which is 0.421 and 0.301, respectively, indicating that digital industry and digital infrastructure have the largest and deepest impact on the development of digital economy. Therefore, we should vigorously develop the digital industry and accelerate the construction of digital infrastructure, so as to promote the rapid development of the digital economy and provide guarantee for the sustainable and healthy development of the ecological environment (Zongxian and Yang, 2021).

4. Empirical analysis

4.1 Model setup and descriptive statistics of variables

In order to test the effect mechanism that digital economy is conducive to the healthy development of ecological environment, this paper establishes an econometric model of panel data based on the selected indicators to verify the validity of this hypothesis (Rong-Tian and JIAO, 2015). In addition, in order to exclude possible heteroscedasticity between data, logarithmic processing was carried out on some variables in the model. Meanwhile, fixed-effect regression model was also adopted for regression analysis. The formula is as follows:

$$\ln EE_{it} = c + \beta_1 \ln DE_{it} + \beta_2 control_{it} + \mu_i + \varepsilon_{it} \quad (7)$$

where i denotes province, t denotes year; EE denotes ecological environment, c is a constant term, and β_1、β_2 is the Undetermined coefficient, and $control_{it}$ is a set of control variables, including industrial structure、human capital level、foreign trade dependence、economic development、environmental regulation and education support, and μ_i is the individual effect, ε_{it} is a random error term.

Considering the availability and completeness of the data, data from 2013 to 2021 were used for 30 provinces except Tibet. Table 5 presents descriptive statistics for the explanatory variables、core explanatory variables and control variables.

4.2 Variable testing

(1) Unit root test

Before conducting empirical testing, in order to alleviate the problem of pseudo regression during the testing process, it is necessary to comprehensively use four unit root tests: LLC、IPS、ADF – Fisher Chi-square and Hadr to test all selected variables to verify the stationarity of the selected data series (Lu, 2023; Wang and Zhang, 2023; Ulucak *et al.*, 2020; Weina *et al.*, 2016). The results are shown in Table 6. According to the results of LLC、IPS、ADF – Fisher Chi-square and Hadr tests, the development level of digital economy、ecological environment quality level、industrial structure、human capital level、foreign trade dependence、economic development、environmental regulation and education support are rejected at significance levels of 1%、5% or 10%, respectively (H0: the sequence is a non-stationary sequence), indicating that all sequences are stationary sequences. Therefore, subsequent regression analysis can be conducted.

(2) Correlation test

Variable	Symbol	Observation	Average value	Standard deviation	Minimum value	Maximum value
Ecological environment	lnEE	270	−1.278	0.157	−1.687	−0.770
Digital economy	lnDE	270	−2.302	0.853	−4.557	−0.343
Economic development	lnED	270	9.945	0.852	7.650	11.73
Industrial structure	IS	270	9.503	5.299	0.230	25.27
Environmental regulation	ER	270	0.001	0.001	0.000	0.010
Educational support strength	Edu	270	0.161	0.026	0.099	0.210
Human capital level	lnHCL	270	7.889	0.274	7.058	8.607
Foreign trade dependence	lnFt	270	−1.816	0.946	−4.874	0.309

Source(s): Chart prepared by authors

Table 5.
Descriptive statistics of variables

Variables and test methods	LLC	IPS	ADF – Fisher Chi-square	Hadri
lnEE	−10.4498***	−3.3021***	−1.9507**	3.8910***
	[0.0000]	[0.0005]	[0.0265]	[0.0000]
lnDE	−5.0739***	−2.0137**	−6.5997***	5.2579***
	[0.0000]	[0.0220]	[0.0000]	[0.0000]
lnED	−3.2571***	−2.7380**	−6.1147***	4.8177***
	[0.0006]	[0.0031]	[0.0000]	[0.0000]
IS	−5,3598***	−2.0056**	−11.6618***	5.1530***
	[0.0000]	[0.0224]	[0.0000]	[0.0000]
ER	−11.4845***	−5.9285***	−8.1923***	13.8960***
	[0.0000]	[0.0000]	[0.0000]	[0.0000]
Edu	−6.7318***	−3.2737***	−7.6185***	8.1786***
	[0.0000]	[0.0005]	[0.0000]	[0.0000]
lnHCL	−4.5653***	−3.7881***	−5.4324***	11.9654***
	[0.0000]	[0.0000]	[0.0000]	[0.0000]
lnGML	−9.7825***	−3.7993***	−15.7638***	1.9274**
	[0.0000]	[0.0001]	[0.0000]	[0.0270]
lnFt	−11.3894***	−2.4777**	−1.9377**	6.5078***
	[0.0000]	[0.0066]	[0.0272]	[0.0000]

Note(s): Use Stata15.0 Compiled by software statistics, ***, **, * represent separately 1%, 5%, 10% Level of significance, [] is a *p*-value
Source(s): Chart prepared by authors

Table 6. Results of variable unit root test

After verifying that the selected data is a stationary series, in order to avoid the possible multicollinearity problem between the core explanatory variable and the control variable, which may lead to bias in the model estimation results, it is necessary to conduct further correlation tests on the core explanatory variable and the control variable. In this paper, two test methods of variable correlation coefficient (CI) and variance inflation factor (VIF) are selected to analyze it (Kalt and Kranzl, 2011). If the correlation coefficient (CI) is greater than the absolute value 0.8, it indicates that there is a multicollinearity problem. Otherwise, there is no multicollinearity problem. However, for the sake of rigor, further verification is needed, that is, if the variance inflation factor (VIF) is greater than 10 or the tolerance value 1/VIF is less than 0.1, it indicates that there may be serious collinearity problems. The test results are shown in Table 7 and Table 8. The results show that the absolute value of the correlation coefficient is 0.716, which is still less than 0.8. In addition, the variovariance inflation factor (VIF) of the variables is up to 9.56, all of which are less than 10, and the mean value is less than 5 (the mean value is 3.84), and the tolerance value 1/VIF of the variables is greater than 0.1. By

	lnEE	lnDE	IS	ER	Edu	lnHCL	lnFt	lnED
lnEE	1							
lnDE	0.363***	1						
IS	0.034	−0.558***	1					
ER	−0.107*	−0.480***	0.076	1				
Edu	−0.119*	0.354***	−0.054	−0.139**	1			
lnHCL	0.036	0.527***	−0.500***	−0.390***	−0.005	1		
lnFt	0.155**	0.632***	−0.531***	−0.256***	0.202***	0.566***	1	
lnED	0.332***	0.716***	−0.426***	−0.396***	0.494***	0.413***	0.547***	1

Source(s): Chart prepared by authors

Table 7. Correlation test of variables

combining the test results of correlation coefficient and variance inflation factor, it can be concluded that there is no multiple commonality between the core explanatory variable and the control variable, and subsequent regression analysis can be conducted.

4.3 Empirical tests and analysis of results

Empirical test: This paper aims to study the impact mechanism of China's digital economy on the healthy development of ecological environment through the analysis of 30 sample provinces. Therefore, the variable coefficient panel model that emphasizes individual differences between different provinces is not suitable for this situation, and the fixed effect model in the variable intercept panel model should be chosen theoretically. The mixed regression model, the fixed effect model and the random effect model were successively used for regression analysis. According to the test results, the mixed regression model used the F statistic to test the model, and the results showed that the intercept terms between individuals were different, so the mixed effect model was not applicable (Schot and Kanger, 2018). The estimated results of the fixed effects model are better than those of the random effects model, and the Hausman test results reject the original hypothesis at 1% significance level, which indicates that there is a correlation between random interference and explanatory variables, so the fixed effects model should be chosen, which is exactly in line with the theoretical expectation. In addition, the time effect may also need to be considered in the setting of the fixed effect model, so the time effect test is carried out. It is found that the result F statistic is not significant at 1% level, so the null hypothesis of "no time effect" is accepted. In addition, the joint significance of individual effects is significant at the level of 1%. The original hypothesis of "no individual effect" is rejected, and the model regression should be set as the existence of individual fixed effect but no time effect. Therefore, the economic significance of each variable is explained in the following paragraphs based on the individual fixed effect model.

Empirical result analysis: As shown in Table 9, Model M1 represents the regression results without adding any control variables, while Model M2-M4 represents the regression results after sequentially adding control variables. The regression coefficient of the core explanatory variable digital economy in Model M1 is 0.0968, which passed the test at a significance level of 1% and has a significant positive relationship. Meanwhile, by sequentially adding control variables such as industrial structure、environmental regulations、foreign trade dependence、economic development、human capital level and educational support to the M2-M4 model, the regression parameters of the digital economy on ecological environment quality are all positive and all have passed the 1% significance level test. According to Model M4, after adding industrial structure、environmental regulations、foreign trade dependence、economic development、human capital level and education support, the

Table 8. Correlation test of variables

	VIF	1/VIF
lnDE	9.56	0.1947
IS	1.96	0.5107
ER	1.58	0.6340
Edu	1.50	0.6685
lnHCL	1.89	0.5283
lnFt	2.01	0.4972
lnED	8.40	0.1191
lnDE	9.56	0.1947

Source(s): Chart Prepared by authors

	(1) M1	(2) M2	(3) M3	(4) M4
lnDE	0.0968***	0.160***	0.194***	0.140***
	(0.022)	(0.019)	(0.030)	(0.034)
IS		0.0189***	0.0135***	0.00968*
		(0.005)	(0.004)	(0.005)
ER		24.13***	30.96***	30.08***
		(7.993)	(6.766)	(7.063)
lnFt			−0.0956**	−0.115***
			(0.039)	(0.038)
lnED			−0.0879**	−0.0964**
			(0.043)	(0.047)
Edu				−1.022**
				(0.408)
lnHCL				0.147*
				(0.078)
_cons	−1.056***	−1.116***	−0.294	−1.325**
	(0.050)	(0.052)	(0.477)	(0.640)
Fixed effect	Yes	Yes	Yes	Yes
N	270	270	270	270
R^2	0.2045	0.3037	0.4009	0.4293
adj. R^2	0.2016	0.2959	0.3896	0.4140
Individual effect	41.3400	41.1500	47.7800	40.8400
	[0.0000]	[0.0000]	[0.0000]	[0.0000]
Time effect	0.3000	0.3600	0.1600	0.2600
	[0.9670]	[0.9394]	[0.9959]	[0.9789]

Note(s): Standard errors in parentheses
$^{*}p < 0.1$, $^{**}p < 0.05$, $^{***}p < 0.01$
Source(s): Chart prepared by authors

Table 9.
Benchmark regression results

regression coefficient of the digital economy is 0.140, indicating that for every 1% increase in the development level of the digital economy, the ecological environment will correspondingly improve by 0.140%. It can be concluded that the higher the level of development of the digital economy, the more conducive it is to the healthy development of the ecological environment. On the one hand, with the widespread application of big data technology, comprehensive data information has been obtained in various aspects and fields of ecological environment monitoring, making real-time tracking of ecological environment indicators possible; On the other hand, the continuous development of digital platform monitoring functions provides more convenient conditions for real-time tracking of ecological environment indicators (Chen and Zhang, 2021). Therefore, real-time tracking of ecological environment indicators can effectively promote resource conservation and rational energy utilization, thereby steadily improving the quality of the ecological environment. At the same time, increasing investment in digital infrastructure, vigorously developing the digital industry, and optimizing the external environment of the digital economy will also help promote the healthy development of the ecological environment. Therefore, hypothesis 1 is verified.

In order to further demonstrate the internal relationship between the development level of digital economy and ecological environment, it is necessary to briefly analyze the influence of control variables on the healthy development of ecological environment. The results show that the degree of dependence on foreign trade、economic development and educational support all inhibit the improvement of eco-environmental quality in model M2-M4, whereas the industrial structure、environmental regulation and human capital level all promote the improvement of eco-environmental quality in model M2-M4. Specifically, see model M4, the influence coefficient of foreign trade dependence on ecological environment quality is −0.115 and passes the significance level test of 1%, that is, every 1% increase in foreign trade dependence, the ecological environment quality will significantly decrease by 0.115%. The possible reason is that the difference between domestic and foreign environmental control is too large, and China's export trade activities are faced with more stringent environmental control and higher access threshold, resulting in higher resource consumption and pollution degree of export products than imported products, which has a great impact on China's ecological environment.

The influence coefficient of economic development on ecological environment quality is −0.0964 and passes the significance level test of 5%, that is, every 1% increase in economic development, the ecological environment quality will significantly decrease by 0.0964%. On the one hand, it may be that with economic growth, the consumption of resources is also increasing, which may lead to resource depletion and ecosystem destruction. On the other hand, industrial production and other activities will produce a large number of pollutants, such as air pollution、 water pollution and soil pollution, which will seriously affect the quality of the ecological environment (Zhang and Zhu, 2017). In addition, the influence coefficient of education support intensity on ecological environment quality is −1.022 and passes the significance level test of 5%, that is, every 1% increase in education support intensity, ecological environment quality will significantly decrease by 1.022%.

The influence coefficient of industrial structure on ecological environment quality was 0.0096 and passed the significance level test of 10%, indicating that the improvement of industrial structure level has a promoting effect on the improvement of ecological environment. The possible reason is that the upgrading of industrial structure can minimize the resource consumption and waste emissions per unit of output in economic growth, and effectively curb the adverse impact of economic development on the ecological environment. The impact coefficient of environmental regulation on ecological environment quality is 30.08 and passes the significance level test of 1%, that is, every 1% increase in environmental regulation, ecological environment quality will be significantly improved by 30.08%. The possible reason is that environmental regulations enhance the environmental awareness and innovation ability of enterprises, thus promoting the green transformation of enterprises. The influence coefficient of human capital level on ecological environment quality was 0.147 and passed the significance level test of 10%, indicating that the improvement of human capital level has a promoting effect on the improvement of ecological environment. The reason may be that human capital invested in environmental technologies and green industries makes the research and application of environmental technologies more efficient and promotes the development and utilization of clean energy.

4.4 Heterogeneity test

Because there are certain differences in both the foundation of digital economy development and the background of ecological environment in different regions, there are obvious heterogeneity characteristics in the quality of digital economy and ecological environment in each region. Therefore, the sample range was changed from the whole country to the eastern, central and western regions, and the heterogeneity among different regions was tested on this basis (Zhu and Zhang, 2020). The results are shown in Table 10. According to the regression results of model M5-M7 in Tables 10, it can be seen that digital economy in different regions still has a promoting effect on ecological environment quality, and regional heterogeneity is obvious, showing the central region > western region > eastern region. That is, compared with the eastern region, the central region and the western region can obtain more benefits from the development of the digital economy, which also shows that under appropriate circumstances, the development of the digital economy is conducive to improving the quality of the ecological environment and narrowing the gap between regions. The reason for this result may be that the development of digital economy in the eastern region of China started earlier, and both the development level and development speed are significantly higher than that of the central and western regions, thus releasing the dividend of the impact of digital economy on ecological environment quality in advance. If you want to use the digital economy to promote the improvement of ecological environment quality, you need a higher level of digital economy development. At the same time, although there are some differences in the estimated value and significance level of each parameter, the positive and negative signs of each parameter are basically the same, and the goodness of fit of each model is also basically the same. Therefore, it can be shown that the digital economy has played a positive role in promoting the healthy development of China's ecological environment, and the differences between various regions are also obvious. Hypothesis 2 is verified.

4.5 Robustness test

The above regional heterogeneity analysis has reflected the robustness of the model to a certain extent, but in order to further verify the scientificity and credibility of the selected regression model, the following three methods need to be adopted for robustness testing, and the results are shown in Table 11. The first is truncated processing, which replaces outliers outside 1%–99% with blank values (see table model M8); The second is indent processing, that is, to find the quantile corresponding to 1 and 99% of each variable, and the variable data corresponding to the replacement component number less than 1% and greater than 99% to prevent large fluctuations in data, resulting in heteroscedasticity (see table model M9); The third is to extend the time window and advance the ecological environment quality of the explained variables by 1 period and 2 periods respectively. The results are shown in Table M10-M11. Therefore, according to model M8-M11 in Tables 11, it can be seen that in

	(1) M5	(2) M6	(3) M7
lnDE	0.181***	0.150**	0.104*
	(0.041)	(0.056)	(0.055)
ER	43.61***	26.74***	72.17***
	(10.439)	(6.802)	(18.740)
lnED	−0.0876	−0.150***	0.183*
	(0.095)	(0.044)	(0.093)
IS	0.00402	0.0287	−2.157***
	(0.007)	(0.135)	(0.486)
lnHCL	0.126	0.0141	−0.0632
	(0.111)	(0.010)	(0.074)
Edu	−0.676	−0.145	0.00832
	(0.715)	(0.157)	(0.023)
lnFt	0.0146	−0.291	−0.0897
	(0.042)	(0.798)	(0.074)
_cons	−0.916	−0.577	−1.704
	(0.751)	(1.204)	(1.166)
N	81	90	99
R^2	0.6443	0.5726	0.4521
adj. R^2	0.6102	0.5361	0.4099

Note(s): Standard errors in parentheses
$^{*}p < 0.1$, $^{**}p < 0.05$, $^{***}p < 0.01$
Source(s): Chart prepared by authors

Table 10. Results of regional heterogeneity

addition to the changes in the coefficients and significance of some control variables, the coincidence and significance of the coefficient of the development level of the digital economy, the core explanatory variable, has not changed greatly, showing strong robustness, indicating that the development level of the digital economy has a significant role in promoting the quality of the ecological environment.

4.6 Endogeneity test

Endogeneity is an unavoidable problem in empirical research. Omission of other variables, bidirectional causality and measurement error all lead to deviation of estimation results. Since both digital economy and ecological environment quality are abstract and complex qualitative problems, it is very likely to produce endogenous problems due to measurement deviation in the process of transformation into quantitative problems. At the same time, although the influencing factors such as industrial structure, environmental regulation, foreign trade dependence, economic development, human capital level and educational support are controlled, there may be other potential influencing factors that are not taken into account, and other variables are missing. In addition, there may also be reverse causality between the ecological environment and the digital economy. For example, in areas with more natural resources, less pollutants and high service level, more complete network infrastructure may be built and there is a higher level of information development, which is easier to promote the rapid development of the digital economy. Therefore, in order to alleviate the endogeneity problem in regression, this paper adopts the instrumental variable method to regression the model. One is to use the lag phase (IV1) of the digital economy as an instrumental variable. Since the impact of the current ecological environment on the digital economy that lags one period is almost zero, if the digital economy that lags one period still maintains the promoting effect on the quality of the ecological environment in the current

	(1) M8	(2) M9	(3) M10	(4) M11
lnDE	0.147***	0.155***	0.122***	0.173***
	(0.041)	(0.035)	(0.037)	(0.057)
ER	37.74**	32.07***	−0.788*	0.00826
	(14.579)	(8.559)	(0.398)	(0.669)
Edu	−0.746*	−0.887**	−0.0975***	−0.0700
	(0.385)	(0.397)	(0.035)	(0.042)
lnFt	−0.0912**	−0.107**	−0.138**	−0.225**
	(0.034)	(0.042)	(0.060)	(0.091)
lnED	−0.0680	−0.102**	4.292	5.136
	(0.051)	(0.047)	(4.202)	(8.291)
IS	0.00945	0.00975*	−0.00138	−0.00996
	(0.006)	(0.005)	(0.006)	(0.009)
lnHCL	0.120	0.131	−0.0120	−0.142
	(0.081)	(0.081)	(0.102)	(0.114)
_cons	−1.385*	−1.114*	0.430	2.448**
	(0.701)	(0.635)	(0.748)	(0.986)
N	244	270	240	210
R^2	0.3658	0.4085	0.2612	0.2080
adj. R^2	0.3470	0.3927	0.2389	0.1805

Note(s): Standard errors in parentheses
$^*p < 0.1$, $^{**}p < 0.05$, $^{***}p < 0.01$
Source(s): Chart prepared by authors

Table 11.
Robustness test results

period, then it indicates that the development of the digital economy is the main reason in this two-way causal relationship. The second is to use the product (IV2) of the first-order difference between the digital economy and the national digital economy with a lag of one phase as an instrumental variable. The results are shown in model M12-M13 in Table 12.

As can be seen from the regression results in Table 12, Kleibergen-PAAP rk LM statistics of all models reject the null hypothesis of "insufficient identification of instrumental variables" at the significance level of 1%. In the test of weak instrumental variable identification, all the Kleibergen-PaAP rk Wald F statistics are greater than the critical value (16.38) at the 10% level of the Stock-Yogo test. The above tests indicate the rationality of the digital economy's one-stage lag (IV1), the product of the first-order difference of the digital economy and the national digital economy (IV2) as the instrumental variables of the digital economy. According to the regression results, after considering the endogenous problem, the positive impact of digital economy on ecological environment quality still exists significantly.

5. Conclusion

Based on the sample data of 30 provinces in China from 2013 to 2021, this study uses fixed effect regression model to study and analyze the healthy development of digital economy on ecological environment. The following conclusions are drawn:

(1) The level of digital economy development has an important role in the healthy development of ecological environment in our country. The results of the fixed effect model show that the digital economy can effectively improve production efficiency, resource utilization and reduce pollutant emissions by integrating and optimizing resource allocation, and play a significant role in promoting the improvement and promotion of the ecological environment.

(2) After the robustness test by changing the sample value range, the result that the development level of digital economy plays a significant role in promoting the healthy development of ecological environment remains valid. At the same time, the test results show that the development level of digital economy has significant regional heterogeneity on the healthy development of ecological environment in China, and the

	(1) M12	(2) M13
lnDE	0.186***	0.166***
	(0.038)	(0.095)
Control variable	Yes	Yes
Individual fixation effect	Yes	Yes
cons	−0.302	−0.792
	(0.604)	(1.691)
N	240	240
R^2	0.8957	0.9030
adj. R^2	0.8772	0.8858
Kleibergen - Paap rk	124.744***	26.298***
LM statistic	[0.0000]	[0.0000]
Kleibergen - Paap rk	297.021	29.060
Wald F statistic	{16.38}	{16.38}

Note(s): Compiled by Stata16.0 software, ***, ** and * represent significance levels of 1%, 5 and 10% respectively, where () is the z value, [] is the p value, {} is the Stock-Yogo Test the critical value at the 10% level
Source(s): Chart prepared by authors

Table 12. Endogeneity test of the impact of digital economy on ecological environment quality

impact of digital economy on ecological environment is most significant in the central region, followed by the western region, and less significant in the eastern region.

(3) The weight analysis of each index based on entropy weight method shows that the digital industry has the greatest impact on the development level of digital economy, and the comprehensive weight is 0.421. The most influential is digital infrastructure, with a comprehensive weight of 0.301; The digital environment has the least impact, with a combined weight of 0.278. Among them, the digital industry is the information technology and communication industry, which provides technology, products and services for the development of the digital economy, and is the core driving force for the rapid development of the digital economy. Therefore, digital industrialization should be vigorously developed to provide impetus for the rapid development of digital economy. In addition, in the process of optimizing the ecological environment, in addition to paying attention to the factors with high weight, the factors with low weight can't be ignored. For example, the digital environment has the lowest weight and the least impact on the digital economy, so it cannot significantly promote the healthy development of the ecological environment, but it still plays an important role in the new development pattern of the digital economy, and its impact on the digital economy cannot be ignored.

References

Cai, S., Gu, C. and Zhang, Z. (2022), "Spatial and temporal characteristics and influencing factors of provincial digital economy in China", *East China Economic Management*, No. 7, pp. 1-9.

Chen, M. and Zhang, S. (2021), "Comparison of living standards of Chinese residents: based on global night light data", *Economic Theory and Management*, No. 05, pp. 48-67.

Chen, S. and Jia, K. (2020), "China's environmental governance research in the context of digital transformation: reflection and innovation of theoretical foundations", *E-Government*, No. 10, pp. 20-28.

Ding, Y. and Qin, Z. (2021), "The impact of information and communication technology on green economy efficiency: an empirical study based on Panel Tobit model", *Learning and Practice*, No. 04, pp. 32-44.

Guo, Q. and Ma, X. (2022), "Research on the impact of digital economy on urban green total factor productivity", *Modern Management Science*, No. 05, pp. 156-166.

Han, J., Chen, Xi and Xiaohu, FENG (2022), "Realistic challenges and path choices of digital economy enabling green development", *Reform*, No. 09, pp. 11-23.

Hagen, RYAN (2018), "The end of ownership:personal property in the digital economy", *Science and Public Policy*, Vol. 45 No. 1, pp. 137-139, doi: 10.1093/scipol/scx033.

He, W., We, J. and Zhang, M. (2022), "Research on the impact of digital economy development on China's green eco-efficiency - based on two-way fixed effect model", *Economic Issues*, No. 1, pp. 86-88+101, doi: 10.19386/j.cnki.jxnyxb.2007.03.031.

Jiao, S. and Sun, Q. (2021), "Research on the measurement of China's digital economy development and its influencing factors", *Research World*, No. 07, pp. 13-23.

Jijun, S., Zhou, J., Chen, Y. and Liu, C. (2022), "Spatial evolution of provincial digital economy and its Urban-Rural integration effect in China", *Economic Geography*, No. 08, pp. 103-111.

Kalt, G. and Kranzl, L. (2011), "Assessing the economic efficiency of bioenergy technologies in climate mitigation and fossil fuel replacement in Austria using a techno-economic approach", *Applied Energy*, Vol. 88 No. 11, pp. 3665-3684, doi: 10.1016/j.apenergy.2011.03.014.

Liu, S. (2022), "Enabling effect of digital technology on China's industrial green transformation and its regional heterogeneity analysis", *Guihai Discussion Series*, Vol. 2022 No. 02, pp. 64-71.

Liu, Q. and Ren, Z. (2007), "Grey comprehensive assessment of regional ecological environment quality in Shaanxi Province", *Jiangxi Journal of Agriculture*, No. 3, pp. 1-8+30, doi: 10.16011/j.cnki.jjwt.2022.01.002.

Liu, Z. and Yanfei, Li. (2023), "An empirical study of China's digital economy development empowering ecological environmental protection", *Productivity Research*, No. 01, pp. 12-20.

Lu, J. (2023), "Research on the heterogeneous impact of digital economy development on the consumption gap between urban and rural residents", *Research on Business Economy*, No. 06, pp. 39-42.

Lu, X. (2015), "The change and regional difference of ecological environment quality in China", *Statistics and Decision*, No. 01, pp. 130-133.

Luo, Q., Cui, G. and Rui, X. (2022), "Coordinated development of digital logistics, economic growth and ecological environment", *Logistics Technology*, No. 10, pp. 53-57.

Pan, W., He, Z. and Pan, H. (2021), "Spatial and temporal evolution and distribution dynamics of China's digital economy development", *China Soft Science*, No. 10, pp. 137-147.

Ren, B. (2020), "Logic, mechanism and path of digital economy leading high-quality development", *Journal of Xi'an University of Finance and Economics*, Vol. 2020 No. 02, pp. 5-9.

Ren, B. and Lv, C. (2019), "Change trend and spatial distribution pattern of ecological and environmental quality in China", *Economic and Management Review*, Vol. 35 No. 03, pp. 120-134.

Rong-Tian, Z. and Jiao, H.-F. (2015), "Analysis of the coupled and coordinated relationship between economic development and ecological environment in the pan-Yangtze River Delta region", *Yangtze River Basin Resources and Environment*, No. 05, pp. 719-727.

Schot, J. and Kanger, L. (2018), "Deep transitions:Emergence,acceleration,stabilization and directionality", *Research Policy*, Vol. 47 No. 06, pp. 1045-1059, doi: 10.1016/j.respol.2018.03.009.

Shujuan, Hu, Peilin, L. and Fan, B.I.E. (2022), "Digital economy, health industry and ecological quality", *Statistics and Decision Making*, No. 21, pp. 15-18.

Tang, B., Lu, B. and Xing, M. (2023), "Measurement of the development level of China's digital economy and analysis of its dynamic evolution", *Mathematical Statistics and Management*, No. 05, pp. 1-14.

Ulucak, R. and Danish and Khan, S.U.D. (2020), "Does information and communication technology affect CO_2 mitigation under the pathway of sustainable development during the mode of globalization?", *Sustainable Devement*, Vol. 28 No. 04, pp. 857-867, doi: 10.1002/sd.2041.

Wang, F. and Zhang, D. (2023), "Impact of digital economy and science and technology innovation on ecological protection - an empirical analysis based on data from 2011 to 2020 in the Yangtze River Economic Belt", *Journal of Changjiang University (Social Science Edition)*, No. 01, pp. 58-67.

Wang, Q.X., Hu, A. and Xin, Y.J. (2022), "Can digital economy promote green development? –An empirical test based on energy saving, emission reduction and efficiency mechanism", *Business Economics and Management*, No. 11, pp. 44-59.

Weina, D., Gilli, M., Mazzanti, M. and Nicolli, F. (2016), "Green inventions and greenhouse gas emission dynamics:A close examination of provincial Italian data", *Environmental Economics and Policy Studies*, Vol. 18 No. 18, pp. 247-263, doi: 10.1007/s10018-015-0126-1.

Xing, Y., Guo, Y. and Wang, L. (2021), "Dynamic measurement of ecological environment quality in China", *Statistics and Decision Making*, Vol. 2021 No. 03, pp. 81-84.

Yang, X. and Zhao, S. (2022), "The low-carbon emission reduction effect of digital economy-enabled regional green development", *Economic and Management Research*, No. 12, pp. 85-100.

Zhang, C. and Zhu, Y. (2017), "Opening up, financial development and interest group dilemma", *World Economy*, No. 04, pp. 55-78.

Zhou, Q. and He, A. (2020), "Digital economy enables high-quality development in the Yellow River Basin", *Economic Issues*, No. 11, pp. 8-17.

Zhu, J. and Pang, W. (2022), "The impact of digital economy development on ecological welfare performance", *Statistics and Decision Making*, No. 24, pp. 79-83.

Zhu, D. and Zhang, Y. (2020), "Theoretical mechanism and empirical study on the impact of China's foreign direct Investment on home environment", *China Population, Resources and Environment*, No. 01, pp. 83-90.

Zongxian, L. and Yang, Q. (2021), "How does the digital economy affect the high-quality development of China's economy?", *Modern Economic Discussion*, No. 07, pp. 10-19.

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