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Does Internet Development Put Pressure on Energy-Saving Potential for Environmental Sustainability? Evidence from China

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ABSTRACT

With the development of information technology and its application in environmental governance, the role of the internet in improving energy efficiency and reducing energy-saving potential (ESP) has attracted more attention. In this study, the slack-based model (SBM) and the unexpected model, along with the entropy method, were applied to measure China's energy-saving potential and internet development. Further, we empirically analyzed the direct effect, mediating effect, threshold effect, and regional heterogeneity of the internet on ESP. Our conclusion shows that there is a significant spatial correlation between internet penetration and ESP. Internet penetration has become an important tool for reducing ESP, but this effect shows regional heterogeneity. Human capital accumulation, financial development, and industrial upgrading are important influencing mechanisms, but indirect effects are weaker than direct effects. The impact of internet penetration on ESP is non-linear, and for improving human capital accumulation, financial development, and industrial upgrading, the role of internet popularization in energy conservation is more obvious.

KEYWORDS

Internet development; Energy-saving potential; Threshold panel model; Spatial Durbin model

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1. Introduction

China's GDP has continued to grow at high speed, creating a growth miracle since the country's economic openness (Hao et al., 2021; Wu et al., 2021a). However, with the gradual growth of the economy, the economic model that relies on the consumption of large amounts of resources is no longer suitable for the current society. Therefore, China urgently needs to change to a new growth model. According to the 19th National Congress of the Communist Party of China, President Xi Jinping proposed the New Development Philosophy, which aims to change China's long-standing inefficient and high-consumption extensive growth model at the expense of the environment. This implies that China is constantly looking for ways to optimize the allocation of resources. As a result, supply-side structural reform, effective resolution of resource mismatch, and reduction of energy-saving potential have become significant problems that need to be urgently solved for the transformation of China's economic development and to achieve sustainable economic growth (Ren et al., 2021; Zhou et al., 2022).

The digital economy has changed the development mode of the traditional economy (Wu et al., 2021b). The Digital Economy Report 2021 pointed out that the cross-border flow of data is mainly concentrated geographically in North America-Europe and North America-Asia. China and the US have the strongest participation ability to benefit from the digital economy. Since early 2016, several Chinese official departments have jointly unveiled the Guiding Opinions on Promoting the Development of Internet + Smart Energy, which kicked off the Chinese national energy Internet development. Also, the Internet is highlighted in terms of its importance in the Key Points of National Standardization Work in 2020 and Guidelines for National Standards Project in 2020 released by the Chinese government in March 2020. The scale of China's digital economy is second only to that of the US, with a year-on-year growth rate of 9.6%, which is far higher than the GDP growth rate. The Internet is open, low-cost, and real-time, which not only promotes energy-saving technology innovation but also realizes intelligent energy management and optimal allocation (Ren et al., 2022a; Zhang et al., 2019). With the advancement of network information technology and energy Internet economy, Internet development, as the driving force of new technology, new formats, and new models, is likely to play a greater role in carbon abatement (Wu et al., 2020).

As the scale of the digital economy increases, the energy Internet + digital economy not only serves to achieve transformation more effectively than the organization and production patterns employed throughout the energy system and energy industry development but also becomes a key driver for leading the energy transformation and even achieving green economic growth (Carlsson, 2004; Vlasov et al., 2018). The digital economy drives an efficient modern energy system, in which intelligent energy system operation, scientific decision-making, and precise services are the primary targets. Furthermore, digital technologies are used to establish an effective operation model as the major form through market-based means and to promote the effective interaction of distributed energy, flexible resources, and energy networks (Ciocoiu, 2011; Litvinenko, 2020). Under the accelerated energy system update, the energy industry was transformed through the digital economy, and an effective path for green economic growth was established with the energy Internet as the link (Sui & Rejeski, 2002; Ali et al., 2018; Kapitonov et al., 2019). Therefore, this study empirically tests the effect of Internet development on energy-saving potential, which is conducive to exploring new ways of energy conservation and provides suggestions for the achievement of sustainable energy development.

This paper attempts to expand on existing research in the following aspects. First, we incorporate the Internet and energy-saving potential into the same research framework. This contributes to a new perspective on emission reduction paths. Second, we construct an index for the comprehensive development level of the Internet from multiple perspectives to accurately measure China's actual Internet development. Finally, we construct a spatial model to explore the spatial effect of the Internet on energy-saving potential. This provides a scientific basis for China to use information technology to control environmental pollution. The research framework is shown in Figure 1.

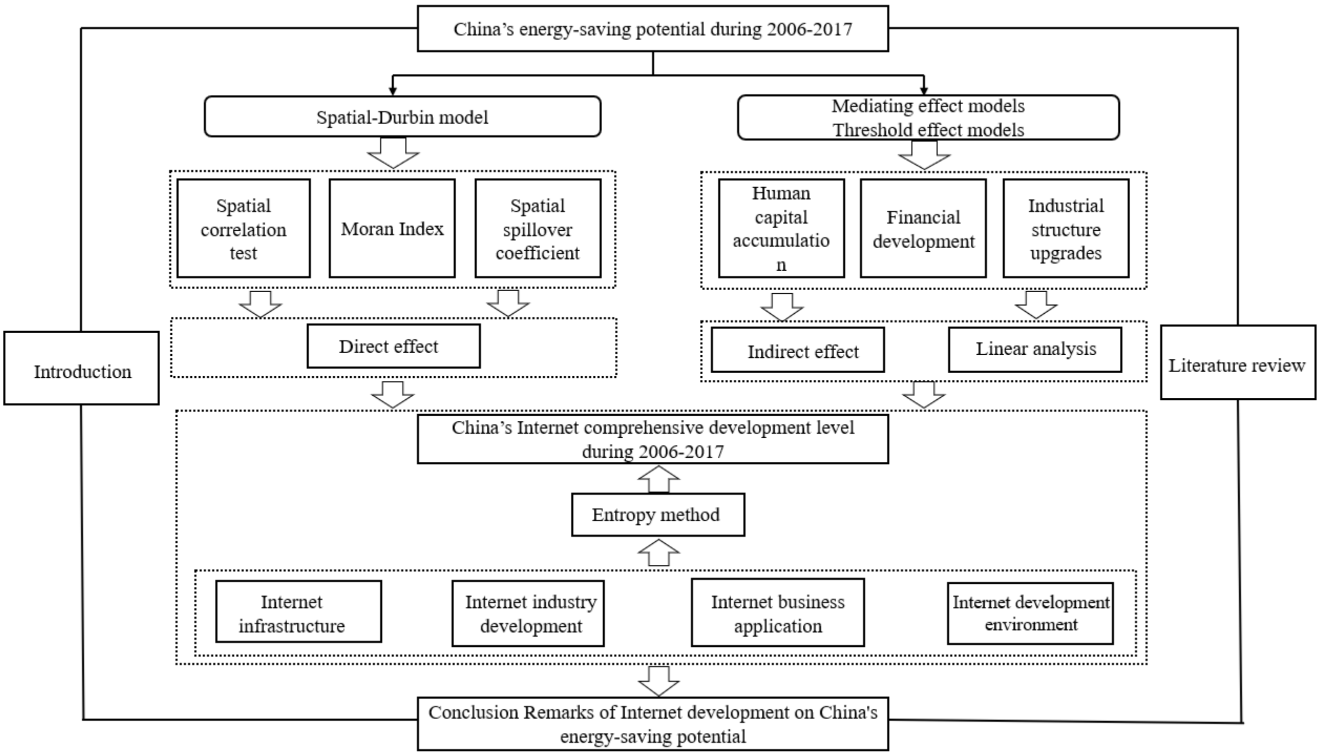


Figure 1. Research framework.

2. Literature review

Green efficiency has double positive externalities for economic and environmental spillovers (Miao et al., 2021; Peng et al., 2021). Green efficiency refers to innovative activities that generate or modify technologies, processes, and products while taking into consideration the limitations of environmental performance. Its goal is to promote the efficiency of energy and resource utilization and ultimately achieve sustainable social development and improved environmental performance (Bartlett & Trifilova, 2010; Fan & Xiao, 2021). With increasingly serious environmental pollution problems, scholars have started to conduct research on green innovation and efficiency (GIE), including GIE under different scales of measurement (Yang et al., 2019), spatial distribution heterogeneity (Li et al., 2015; Liu et al., 2021), spatial aggregation and convergence (Dong et al., 2021; Li & Fu, 2015; Zhou et al., 2021), and other aspects (Fan & Xiao, 2021; Li & Du, 2020; Wang et al., 2018). In the literature on efficiency research, some scholars have calculated green efficiency and analyzed its influencing factors in different research objects such as provinces (Wu et al., 2021; Zhao et al., 2021), industries (He et al., 2021), and cities (Zeng et al., 2021). Many scholars commonly use the DEA model in their studies on efficiency measurement methods. Luo et al. (2019) established the Malmquist-DEA index, and Zhang et al. (2021) employed the network EBM to calculate the GIEs of China's strategic emerging industries and construction industry, respectively. Fan and Xiao (2021) adopted the SBM-DDF, and Zhang et al. (2020) constructed the super-SBM (slack-based model) to calculate the green economic efficiency of 30 Chinese provinces (including municipalities under the central government and autonomous regions). Lin et al. (2021) proposed a two-stage DEA to evaluate the green innovation efficiency in Chinese energy-intensive industries. In studies on influencing factors, most researchers believe that environmental regulation (Wu et al., 2020), government R&D support (Li & Zeng, 2020), industrial structure (Dong et al., 2021), and marketization are the primary factors influencing green efficiency.

With the deepening of digitalization relying on Internet development (INT), the integration of INT and traditional industries has increasingly become the engine of green economic growth (Kim et al., 2021). To promote INT, China has implemented some new policies, like Broadband China, Internet plus, etc. It is widely believed that INT exerts an enormous impact on energy efficiency, environmental supervision, and carbon reduction (Yang et al., 2021; Wu et al., 2021; Ren et al., 2021; Hu et al., 2022; Khan et al., 2022). However, the relevant literature has not reached a consensus on the relationships between INT and CO2 emissions. Current academics have mainly confirmed three relationships, namely, positive, negative, and nonlinear (Khan et al., 2022; Faisa et al., 2020). Besides, scholars have believed that INT and CO2 emissions have spatial spillovers (Shahnazi & Shabani, 2019; Liu et al., 2021). However, the current literature only highlighted their static relationship. Obviously, ignoring the spillover effects may not precisely identify the real relationship. Finally, previous studies have focused on the relationship between INT and CO2 emissions in developed countries but paid little attention to developing countries like China. In recent years, some predecessors have applied China's provincial-level panels to investigate the relationship (Chen et al., 2019). However, different provinces in China have large spatial and internal differences, and there are significant environmental gaps between cities due to their differences in urbanization and industrialization (Cheng et al., 2017). Provincial-level data may lead to estimation errors and biased results. Therefore, we mainly discuss the impact of INT on ESP, as well as the spatial effect. In addition, we also discuss the mechanism and heterogeneity of the impact of INT on ESP.

3. Mechanism analysis

3.1. Direct effect of the Internet on energy-saving potential

The Internet is not only a tool for information transmission but also an important carrier of technology re-creation. The penetration of the Internet has changed the existing technological innovation and energy-saving model. The advantages of the Internet, such as cross-space-time information dissemination, information sharing, and nearly zero cost, effectively solve the contradiction of resource reinvestment in traditional energy conservation. As a technology, the Internet reduces the time and space constraints of information flow and is conducive to the consolidation and processing of fragmented information. People can obtain information through the Internet and reprocess it further (Li et al., 2008). The Internet maximizes the speed of information resources, spreads them in an economic, intuitive, and effective way, and changes the way of obtaining and producing many energy-saving elements. Information dissemination contributes to the accumulation of social knowledge. During information sharing and knowledge multiplication, the Internet has not only fundamentally changed the backward innovation methods of traditional industries but also promoted the continuous innovation of innovation methods of emerging industries, thus promoting the innovation efficiency level of enterprises (Yamakami, 2008). Moreover, the improvement of environmental information not only realizes the effective integration of resources but also facilitates environmental supervision. In addition, the popularity of Internet technology enriches the ways social subjects participate in environmental supervision. Social entities can effectively use the Internet to monitor enterprises' energy applications and excessive emissions, which reduces pollution emissions.

3.2. Indirect effect of the Internet on energy-saving potential

In the process of technology R&D, application, and diffusion, the Internet will inevitably indirectly affect the use and allocation of labor, capital, and technology. First, the Internet provides a convenient way to access information, facilitating knowledge spillover in different regions (Smith, 2000). People can share information and knowledge at any time and exchange research results. This not only reduces the cost of achievement conversion and enterprises' learning but also accelerates the agglomeration of human capital among enterprises. The improvement of the human capital level can help enterprises innovate technology (Shrouf et al., 2014). Second, technological innovation activities require extensive resource investment and carry great risks. The direct financing channel of the Internet has expanded a new way for the preparation of energy-saving funds. People can effectively acquire information on the supply and demand of funds through the Internet, allocate funds reasonably, and expand the scale of financial supply and demand (Powell, 2004; Chen et al., 2017). This undoubtedly indirectly contributes to the innovation activities of enterprises. Finally, the Internet optimizes the configuration of elements and improves their use efficiency in the application field. It not only promotes the upgrading of the industrial chain to the mid-to-high end but also innovates more new products, which are conducive to the emergence of new industries (Cheong & Wu, 2014). In addition, industrial upgrading in the technical field has put forward higher demands on Internet services in the fields of R&D and production (Wan et al., 2017), which further promotes innovative activities and reduces energy-saving potential.

4. Measurement of energy-saving potential

4.1. Measurement method of energy-saving potential

The DEA method is used to measure the relative efficiency of decision-making units (DMUs) by constructing the non-parametric linear production frontier of DMUs (Du et al., 2022). However, in the actual production process, many outputs are "undesirable outputs," such as industrial waste (waste gas, wastewater, waste residue), that are not expected. If they are not taken into account, the efficiency of DMUs cannot be accurately reflected. On this basis, the SBM model was first presented by Tone (2001), and later Tone (2002) proposed the SBM undesirable model to deal with unexpected outputs. However, many scholars have found that when the efficiency of DMUs reaches 1, the optimal efficiency of DMU cannot be distinguished. The super-efficiency SBM model makes the efficiency value of DMUs more accurate and scientific (Tone, 2004). The formula is as follows.

$$\alpha^* = min\frac{\frac{1}{m}\sum_{i=1}^{m}\frac{\bar{x}}{x_{i0}}}{1+\frac{1}{s_1+s_2}\left(\sum_{r=1}^{s_1}\frac{S_r^g}{y_{r,0}^g}+\sum_{r=1}^{s_2}\frac{S_r^b}{y_{r,0}^b}\right)}$$

$$\text{S.t.}\begin{cases}\bar{x} \geq X\lambda \\ \overline{y^g} \leq Y^g\lambda \\ \overline{y^b} \leq Y^b\lambda \\ \bar{x} \geq x_0, \overline{y^g} \leq y_{0,}\overline{y^b} \geq y_{0,}^b\lambda > 0\end{cases}$$

Using the above methods, we can calculate energy consumption investment redundancy and then calculate the energy-saving potential data of China.

$$Ecp_{it} = \frac{LEI_{it}}{EU_{it}} = \frac{EU_{it}\text{-}TEL_{it}}{EU_{it}}$$

Where LEI represents the redundancy of energy consumption input, TEL represents the optimal energy consumption input, and EU represents the actual energy consumption input. Here, i and t denote each province and year, respectively. The calculation results are shown in Table 1.

The model includes input, expected output, and unexpected output variables (Lu et al., 2013; Hao et al., 2022; Ren et al., 2022b). Input variables include capital, labor force, and energy consumption; expected output variables include GDP, and unexpected output variables include wastewater discharge, exhaust gas discharge, and solid waste production. The measurement method for the variables can be seen in Table 1: Measurement System for China's Inter-Provincial Comprehensive Energy-Saving Potential in this paper.

4.2. Analysis of China's energy-saving potential

Table 1. China's energy-saving potential in 2006-2017.

Province	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	Mean	Rank
Beijing	0.433	0.321	0.285	0.124	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.097	29
Tianjin	0.524	0.500	0.476	0.452	0.431	0.398	0.383	0.290	0.251	0.000	0.023	0.000	0.311	24
Hebei	0.715	0.710	0.705	0.701	0.696	0.684	0.662	0.627	0.598	0.572	0.549	0.522	0.645	8
Liaoning	0.603	0.601	0.598	0.596	0.592	0.578	0.554	0.475	0.446	0.426	0.381	0.344	0.516	12
Shanghai	0.415	0.386	0.335	0.303	0.291	0.237	0.186	0.117	0.000	0.018	0.011	0.009	0.192	28
Jiangsu	0.426	0.412	0.394	0.375	0.353	0.329	0.294	0.235	0.187	0.129	0.094	0.048	0.273	25
Zhejiang	0.392	0.373	0.354	0.336	0.311	0.312	0.274	0.238	0.189	0.159	0.131	0.097	0.264	26
Fujian	0.325	0.315	0.316	0.303	0.32	0.297	0.255	0.173	0.16	0.090	0.052	0.005	0.218	27
Shandong	0.624	0.603	0.582	0.561	0.539	0.520	0.497	0.394	0.362	0.337	0.283	0.237	0.461	18
Guangdong	0.000	0.001	0.003	0.000	0.000	0.000	0.002	0.000	0.000	0.031	0.021	0.025	0.007	30
Hainan	0.397	0.382	0.376	0.364	0.345	0.377	0.355	0.305	0.287	0.278	0.263	0.250	0.332	23
Shanxi	0.839	0.831	0.823	0.815	0.807	0.8	0.791	0.777	0.768	0.755	0.746	0.735	0.791	3
Anhui	0.515	0.502	0.498	0.485	0.478	0.456	0.432	0.391	0.353	0.315	0.288	0.254	0.414	21
Jilin	0.635	0.612	0.597	0.578	0.560	0.544	0.508	0.418	0.374	0.300	0.261	0.206	0.466	16
Heilongjiang	0.506	0.504	0.505	0.501	0.499	0.506	0.500	0.419	0.391	0.360	0.334	0.302	0.444	20
Jiangxi	0.497	0.476	0.454	0.438	0.429	0.411	0.374	0.342	0.321	0.293	0.263	0.235	0.378	22
Henan	0.593	0.591	0.587	0.585	0.584	0.567	0.535	0.453	0.43	0.390	0.347	0.305	0.497	14
Hubei	0.661	0.644	0.627	0.610	0.593	0.577	0.559	0.453	0.423	0.375	0.331	0.283	0.511	13
Hunan	0.547	0.545	0.556	0.552	0.541	0.558	0.533	0.423	0.385	0.339	0.299	0.252	0.461	19
Inner Mongolia	0.791	0.78	0.760	0.759	0.747	0.741	0.726	0.666	0.652	0.62	0.596	0.568	0.701	6
Guangxi	0.534	0.531	0.53	0.529	0.527	0.51	0.488	0.433	0.411	0.380	0.349	0.318	0.462	17
Chongqing	0.637	0.62	0.603	0.586	0.569	0.552	0.518	0.376	0.352	0.308	0.277	0.243	0.470	15
Sichuan	0.638	0.627	0.616	0.608	0.602	0.584	0.552	0.472	0.446	0.403	0.361	0.318	0.519	11
Guizhou	0.768	0.775	0.782	0.786	0.794	0.786	0.777	0.734	0.717	0.695	0.676	0.655	0.745	5
Yunnan	0.698	0.686	0.674	0.662	0.65	0.638	0.626	0.565	0.547	0.503	0.481	0.451	0.598	9
Shaanxi	0.666	0.652	0.637	0.623	0.608	0.594	0.579	0.532	0.514	0.498	0.481	0.464	0.571	10
Gansu	0.684	0.686	0.695	0.701	0.717	0.71	0.697	0.677	0.659	0.632	0.622	0.605	0.674	7
Qinghai	0.834	0.832	0.829	0.827	0.813	0.829	0.826	0.82	0.814	0.806	0.809	0.807	0.820	2
Ningxia	0.881	0.877	0.873	0.870	0.862	0.868	0.861	0.854	0.848	0.85	0.844	0.841	0.861	1
Xinjiang	0.738	0.744	0.750	0.756	0.753	0.769	0.783	0.791	0.790	0.782	0.800	0.806	0.772	4
Eastern	0.473	0.459	0.441	0.424	0.406	0.395	0.372	0.309	0.274	0.241	0.303	0.291	0.366	4
Central	0.652	0.647	0.628	0.61	0.599	0.589	0.566	0.501	0.473	0.435	0.529	0.523	0.563	2
Western	0.717	0.717	0.705	0.688	0.675	0.668	0.654	0.607	0.591	0.565	0.635	0.633	0.655	1
Nation	0.578	0.568	0.552	0.535	0.52	0.512	0.493	0.434	0.407	0.375	0.443	0.434	0.488	3

The energy-saving potential of China is presented in Table 1. The overall ESP performance in China is decreasing, with a decreasing trend from the western region to the eastern region. Comparing the energy-saving potential values of the three regions, we can see that the ESP in the western region is the largest, and the smallest is in the eastern region. Overall, except for the eastern region, the energy-saving potential of other regions is higher than the national average value (Li & Lin, 2015). This is mainly due to the advantageous geographical location, developed economy, and high technology level in the eastern region. China has many supporting policies for the development of the eastern region. These factors not only accumulate huge potential for its rapid development but also provide a guarantee for the effective use of energy. The ESP of the central region reduced from 0.625 in 2005 to 0.523 in 2017. In recent years, the central region has been actively changing the mode of economic development, adjusting the industrial structure, and upgrading the technical level, so the potential for energy conservation has been reduced to a certain extent. The highest ESP in the western region is 0.655. This is related to the poor technical conditions and low efficiency of resource allocation in the western region, thus forming an extensive growth mode.

5. Methodology and data

5.1. Model settings

5.1.1. Spatial Durbin model

Previous studies focused on the ESP with non-spatial spillover factors but ignored the spatial interaction. We use the spatial model to study the space of the Internet and ESP. The following dynamic space Doberman model is constructed:

$$Esp_{it} = \alpha_0 + \rho \sum_{j=1}^{N} W_{ijt} Esp_{it} + \alpha_1 Esp_{it-1} + \alpha_2 int_{it} + \alpha_3 \sum_{i \neq j}^{N} W_{ijt}\, int_{it} + \sum_{k=1}^{8} \delta_k X_{it} + \mu_i + \theta_t + \varepsilon_{it} \quad (1)$$

Among them, Esp_{it} is the energy-saving potential; int_{it} is the Internet index; X includes some control variables; W_{it} is a space weight matrix.

5.1.2. Mediation effect models

In order to test the existence of mediation variables, we construct the estimation of mediation effects shown in equations (2), (3), and (4) (Baron & Kenny, 1986).

$$Esp_{it} = \gamma_0 + \gamma_1 int_{it} + \sum_{k=3}^{10} \gamma_k X_{it} + \mu_i + \theta_t + \varepsilon_{it} \quad (2)$$

$$med_{it} = \vartheta_0 + \vartheta_1 int_{it} + \sum_{k=3}^{10} \vartheta_k X_{it} + \mu_i + \theta_t + \varepsilon_{it} \quad (3)$$

$$Esp_{it} = \varphi_0 + \varphi_1 int_{it} + \varphi_2 med_{it} + \sum_{k=3}^{10} \varphi_k X_{it} + \mu_i + \theta_t + \varepsilon_{it} \quad (4)$$

Here, med_{it} is the mediation variable, including human capital accumulation (hr_{it}), financial development (fd_{it}) and industrial structure upgrades (str_{it}).

5.1.3. Threshold effect model

To further test the threshold effect of Internet on ESP, we set up the threshold model.

$$Esp_{it} = \beta_0 + \beta_1 int_{it} \bullet I(int_{it} \leq \gamma) + \beta_2 int_{it} \bullet I(int_{it} > \gamma) + \beta_c X_{it} + \lambda_i + \varepsilon_{it} \quad (5)$$

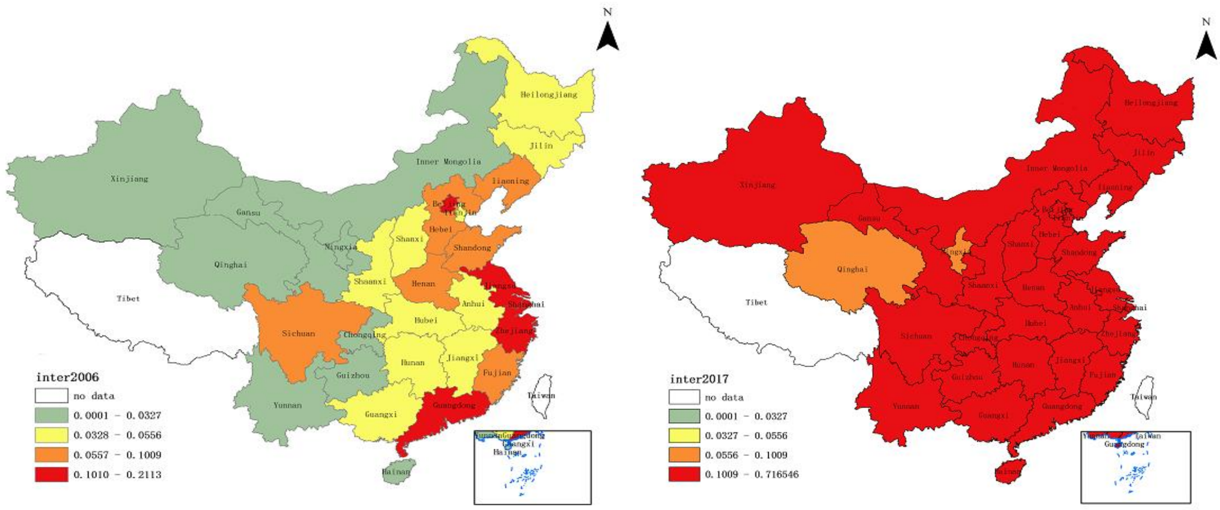
5.2. Variable selection

5.2.1. Energy-saving potential

The calculation method and results of energy-saving potential have been described in detail in Section 3. However, it should be noted that the higher the energy-saving potential, the greater the gap between actual energy efficiency and optimal energy efficiency in the region.

5.2.2. Internet development

This paper constructs China's inter-provincial Internet index based on Internet infrastructure, industry development, business application, and development environment (Wu et al., 2021). As shown in Figure 2, the red area has the highest Internet level among the 30 provinces in China, indicating that the Internet level in western China is relatively low, followed by central China, while the Internet level in eastern China is the highest, particularly in the eastern provinces of Beijing and Guangdong. From 2006 to 2017, the red area gradually increased, indicating that China's Internet level is increasing.



int 2006 int 2017

Figure 2. Internet development in China.

5.2.3. Mediation variable

This paper selects human capital accumulation (hc), financial development (fd), and industrial structure upgrading (str) as mediation variables to empirically test the indirect impact mechanism of the Internet on energy-saving potential. Among them, human capital is measured by the average years of education among provinces; financial development is measured by the ratio of the year-end deposit balance of financial institutions to GDP; industrial upgrading is measured by the ratio of the output value of the tertiary industry to the secondary industry among provinces.

5.2.4. Control variables

This paper introduces a set of related control variables, including economic openness (od), which uses the proportion of FDI in GDP of each province to measure the degree of openness. Urbanization level (urb), which uses the proportion of non-agricultural population in each province to measure the level of urbanization. R&D investment intensity (rd), which is measured by the proportion of R&D investment in GDP of each province. Enterprise labor (soe): the ratio of the number of employees of non-state-owned enterprises to the total number of employees is adopted to reflect the degree of SOE (Table 2).

Table 2. The statistical description of variables.

Variable	Definition	Obs	Mean	Std. Dev.	Min	Max
Ecp	Energy-saving potential	360	0.482	0.233	0.000	0.881
int	Connected development level	360	0.083	0.057	0.016	0.209
fd	Financial development	360	1.659	0.733	0.108	5.587
hr	Human capital accumulation	360	8.800	0.980	6.594	12.502
str	Industrial structural upgrade	360	0.476	0.089	0.333	0.809
urban	Urbanization level	360	0.535	0.137	0.275	0.896
od	Open to the outside world	360	0.057	0.073	0.008	0.75
soe	Corporate labor	360	0.708	0.106	0.440	0.899
rd	R&D investment intensity	360	0.015	0.011	0.002	0.060

6. Empirical results

6.1. Estimation results of spatial model

6.1.1. Spatial correlation test

We report the Moran's I of variables under the weight matrix of geographical proximity. The results show that the Moran's I of China's ESP and Internet level in 2006-2017 is positive. According to the Moran scatter plot in Figure 3, the ESP and Internet level exhibit significant spatial agglomeration characteristics.

Table 3. Global correlation test.

Time	Esp			Inter		
	I	z	p-value	I	z	p-value
2006	0.324***	3.457	0.001	0.324***	3.457	0.001
2007	0.306***	3.287	0.001	0.324***	3.457	0.001
2008	0.308***	3.251	0.001	0.306***	3.287	0.001
2009	0.286***	3.015	0.003	0.308***	3.251	0.001
2010	0.256***	2.727	0.006	0.256***	2.727	0.006
2011	0.240***	2.577	0.010	0.240***	2.577	0.010
2012	0.235**	2.524	0.012	0.235**	2.524	0.012
2013	0.259***	2.728	0.006	0.259***	2.728	0.006
2014	0.260***	2.729	0.006	0.260***	2.729	0.006
2015	0.293***	3.015	0.003	0.293***	3.015	0.003
2016	0.285***	2.937	0.003	0.285***	2.937	0.003
2017	0.301***	3.088	0.002	0.301***	3.088	0.002

6.1.2. Results of the spatial effect

We report the estimation results of non-spatial panel models OLS, RE, System-GMM, and Differential-GMM in Table 4. The R2 is 0.6502, showing a high overall fitting degree. In the geographical and economic matrices, ρ is significantly positive at a 1% confidence level, indicating a significant spatial interaction between the Internet and energy-saving potential. This suggests that the development of the Internet and energy-saving potential are not only influenced by their own factors but also by regions with similar geographical or economic development levels. In addition, although both spatial and non-spatial panel models are used for regression, the coefficients of int are relatively consistent.

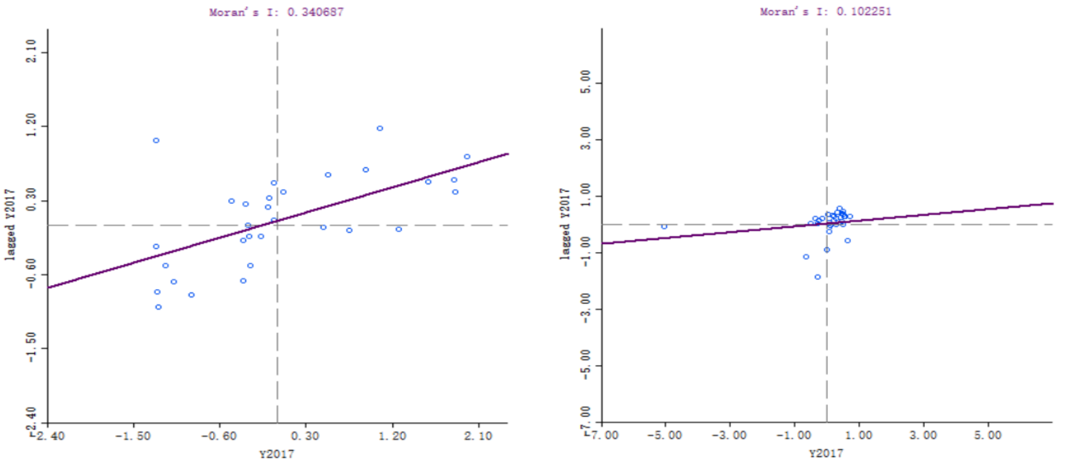


Figure 3. Scatter plot of the Moran index in 2005 and 2016.

The significantly negative coefficient of int verifies Hypothesis 1, indicating that the Internet can significantly reduce regional energy-saving potential, which supports the research conclusion of Zia (2016) to some extent. The reasons are as follows: firstly, the Internet effectively promotes the high-speed transmission of information in the regional innovation system and breaks the space-time constraints of information transmission. This provides massive and high-quality information for the innovation activities of enterprises in the process of energy consumption and improves the application level of energy informatization, which enables effective scheduling and resource sharing of various resources. Therefore, it promotes regional energy use efficiency and reduces energy consumption. Secondly, the spillover effect of the Internet can promote the continued diffusion and widespread application of innovative technologies in the application sector. This process makes it easier for the subject of innovation to enjoy efficient innovation services (Li et al., 2008), which promotes the emergence and exchange of innovative thinking and the commercialization ability of new technologies. Besides, the proliferation of the Internet in other fields not only fundamentally changes the backward innovation methods of traditional industries but also promotes the continuous innovation of innovative methods in emerging industries. This is conducive to promoting the level of innovation efficiency of the entire society. Finally, although China is gradually moving towards a diversified model of environmental governance, the government is still the main body of environmental governance. The popularization of the Internet has realized the dynamic monitoring and informatization of the environment, broadened the way of citizens' environmental supervision, improved production technology, and reduced the ESP of the entire industry.

6.2. Estimation results of mediation effect

The mechanism by which the Internet affects ESP is discussed from three aspects: human capital accumulation, financial development, and industrial upgrading. The estimation results with human capital accumulation as the mediating variable show that the Internet promotes the accumulation of human capital. The impact coefficient of human capital on energy-saving potential is -0.124, indicating that the Internet can indirectly promote the reduction of energy-saving potential through the accumulation of human capital. It promotes technology research and development, improves productivity, and reduces energy consumption. Model (3) and Model (4) estimate financial development as the mediating variable. The impact coefficient of the Internet on financial development is positive (2.986), and the impact coefficient of financial development on energy-saving potential is -0.105, indicating that the Internet indirectly reduces energy-saving potential through efficient financial development. The reason is that innovation activities have high investment and risk and require a large amount of capital for the normal operation

Table 4. The regression results of direct effects.

Variable	OLS	RE	SYS-GMM	DIF-GMM	SDM	SAR
Int	-0.624***	-1.058***	-0.036*	-0.666***	-0.939**	-0.808***
	(-4.421)	(-9.886)	(-1.905)	(-19.494)	(-2.284)	(-5.727)
Urban	-0.262***	0.162	0.021	-0.114**	0.812***	0.163
	(-2.682)	(1.233)	(1.195)	(-2.227)	(4.416)	(1.321)
Od	-0.638***	0.008	0.140***	0.044**	0.016	0.003
	(-5.443)	(0.125)	(4.055)	(2.468)	(0.257)	(0.047)
soe	-0.774***	-0.303***	-0.300***	0.006	-0.175**	-0.289***
	(-10.111)	(-4.230)	(-38.929)	(0.640)	(-2.531)	(-4.277)
rd	-6.935***	-10.851***	-1.874***	-7.645***	-3.036	-9.623***
	(-6.294)	(-7.064)	(-13.632)	(-18.041)	(-1.628)	(-6.319)
cons	1.359***	0.855***	0.238***			
	(23.761)	(11.153)	(21.051)			
ρ					0.230***	0.212**
					(2.927)	(2.514)
AR(1)			-1.88	-0.81		
			[0.060]	[0.416]		
AR(2)			0.83	1.59		
			[0.406]	[0.112]		
Hansen			27.86	25.95		
			[0.266]	[0.101]		
R2/Wald	0.6502		642801.23***	2884.41***		
N	360	360	360	360	360	360

*Note: * p < 0.1, ** p < 0.05, *** p < 0.01.*

of technology R&D activities. However, the openness and timeliness of the Internet facilitate enterprises to obtain capital information in a timely manner. The combination of the Internet and finance also accelerates the high-speed operation of funds and provides stable financial support for enterprises' innovation activities. It improves the efficiency of capital allocation and the speed of capital flow, promotes the technology R&D of enterprises, and reduces the potential for energy conservation. Models (5) and (6) show that the Internet can indirectly reduce energy-saving potential by driving industrial upgrading. The Internet can serve as the foundation and support for the development of the Internet industry and can also be used as a new technology to invest in traditional industries and optimize traditional production relations (Price et al., 2010). It effectively promotes the development and transformation of traditional industries and provides technical support for their transformation. In addition, the technological bias effect created by the Internet can reduce the size of enterprises and, to a certain extent, reduce high energy consumption, save labor, and increase enterprise production efficiency, thus reducing energy consumption. The above research results confirm the conclusion that the Internet has a mediating effect on reducing energy-saving potential, which supports the basic conclusion that the Internet can become a significant driving force for emission reduction in China.

6.3. Estimation results of the threshold effect

Furthermore, how will the impact of the Internet on ESP change with the development of human capital, finance, and industrial structure? To this end, we draw on the threshold model proposed by Hansen (1999) and use them as threshold variables to verify the nonlinear effect between the Internet and energy-saving potential. Before the threshold effect analysis, we test for the existence of thresholds and the number of possible thresholds using the bootstrap method. Table 6 shows that three threshold variables have passed the double threshold test, indicating that the relationship between the Internet and regional energy-saving potential is nonlinear.

Table 5. The results of the mediation effect.

Variable	(1)	(2)	(3)	(4)	(5)	(6)
	hr	ESP	fd	ESP	str	ESP
Int	6.267***	-0.629***	2.986***	-1.093***	0.634***	-0.721***
	(7.40)	(-3.38)	(4.52)	(-5.58)	(8.34)	(-3.56)
hr		-0.124***				
		(-11.49)				
fd				-0.105***		
				(-6.92)		
str						-1.083***
						(-8.42)
cons	8.28***	1.627***	1.411***	0.747***	0.424***	1.058***
	(97.31)	(17.86)	(21.23)	(26.01)	(55.5)	(18.37)
N	360	360	360	360	360	360

*Note: * p < 0.1, ** p < 0.05, *** p < 0.01.*

Table 6. The results of threshold model.

variable	Threshold order	F-value	P-value	Threshold	Critical value		
	Single threshold	43.315	0.113	8.279	84.634	56.380	44.770
hr	Double threshold	25.162***	0.010	and	24.979	12.715	8.483
	Third threshold	0.000	0.327	10.455	0.000	0.000	0.000
	Single threshold	69.281***	0.000	1.473	53.661	24.470	18.389
fd	Double threshold	26.210***	0.000	and	1.247	-20.579	-28.614
	Third threshold	0.000	0.250	2.365	0.000	0.000	0.000
	Single threshold	8.027*	0.090	0.471	12.852	10.210	7.557
str	Double threshold	17.760**	0.040	and	36.785	15.476	10.171
	Third threshold	0.000	0.247	0.615	0.000	0.000	0.000

*Note: * p < 0.1, ** p < 0.05, *** p < 0.01.*

The results in Table 7 indicate that, in terms of human capital accumulation, the negative impact of the Internet on ESP gradually increases when the regional human capital accumulation level successively crosses the thresholds of 8.279 and 10.455. This suggests that a high level of human capital is more conducive to promoting technological innovation on the Internet, thereby improving the energy efficiency of enterprises and reducing ESP. With regard to financial development, the coefficient of the impact of the Internet on ESP changes from -0.800 to -1.158 when the regional financial development level successively crosses the threshold values of 1.473 and 2.365. This indicates that regional financial development can not only alleviate investment and financing constraints for local enterprises but also provide good external financing conditions for their innovation activities. Regarding industrial structure upgrading, the threshold effect of the Internet on regional energy-saving potential changes from -0.453 to -1.295. This implies that industrial upgrading not only improves the allocation of production factors in traditional industries but also accelerates the integration of networking and low-carbon industries, thereby further reducing the energy-saving potential.

6.4. Robustness test and regional analysis

Endogeneity treatment has always been a difficult problem in empirical research in economics. Missing variables and reciprocal causality may lead to endogeneity problems (Barro & Lee, 1994). In this paper, we address some possible endogeneity problems. First, to address endogeneity caused by measurement error, we use the SBM-undesirable model to measure the energy-saving potential. When calculating the Internet level under multiple indicators, we use the entropy method to reduce the problem of information overlap between multiple indicators.

Table 7. The regression results of the threshold model.

variable	hr	fd	str
urban	-0.645*** (-9.22)	-0.801*** (-8.14)	-0.706*** (-7.06)
od	0.048 (0.76)	-0.429*** (-5.27)	0.260*** (-3.43)
soe	0.187*** (2.78)	-0.336*** (-4.08)	-0.151** (-1.73)
rd	1.999** (1.69)	-7.258*** (-4.50)	-4.062*** (-4.06)
Int_1	-0.483*** (-3.66)	-0.800*** (-5.97)	-0.453*** (-3.32)
Int_2	-0.982*** (-13.45)	-0.304*** (-2.66)	-0.687*** (-6.78)
Int_3	-2.712*** (-15.04)	-1.158*** (-4.60)	-1.295*** (-7.51)
Cons	0.750*** (14.07)	1.326*** (21.78)	1.094*** (16.57)
N	360	360	360

*Note: * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.*

Second, to address the endogeneity problem caused by missing variables, we add human capital, finance, and industrial structure upgrading as control variables into the model. To prevent measurement model setting error and endogeneity, we construct a dynamic panel model by introducing a lag term and using the differential GMM method for regression.

In addition, over-concentration of resources has been shown to cause regional development imbalances. Due to the huge differences in the natural environment, development mode, and even economic basis of each province in China, there are typical heterogeneity features in economic development planning, economic policy implementation, and policy effects among provinces (Shen, 2004). This heterogeneity makes the positive effect of the Internet on ESP significantly different in different regions. To verify the existence of heterogeneity, we divided the total sample into three subsamples to test the impact of Internet penetration on ESP in different regions. Table 8 shows that Internet penetration has a negative impact on the ESP in the eastern, central, and western regions. Moreover, this effect is more significant in the eastern region, followed by the central region, and the coefficient in the western region is not significant. Under the influence of the Internet, new technologies, new industries, and new models are rising rapidly and growing in various regions, but there are regional differences in Internet development (Qian, 2015). The superior location advantage of the eastern region makes it a developed area of Internet technology. The polarization effect of growth accelerates the concentration of funds, energy, information, and talents to the Internet technology-developed areas, and then transmits the Internet technology and innovation results to the surrounding areas (Ning et al., 2010). However, due to the limited economic strength and the concentration of factors, in the process of Internet development, the Internet infrastructure in the western region is significantly different from that in other regions (Ma et al., 2014). Internet is changing the comprehensive strength of each region, but there is a huge gap in the input, innovation output, and technology application of Internet development in each region, which may lead to a growing difference in ESP in each region. Through the above tests, including the Internet coefficient results, we maintained good consistency, which shows that the main conclusions of this paper have good robustness.

7. Conclusions and policy recommendation

This paper estimates the comprehensive development and energy-saving potential of China's Internet. We study the influence path of the Internet on ESP through the direct effect, mediation effect, and threshold effect. The results show that the popularity of the Internet reduces the energy-saving potential. The Internet can indirectly reduce ESP through human capital accumulation, finance, and industrial upgrading. When the threshold is exceeded, the impact of the Internet on ESP gradually strengthens. There is regional heterogeneity in the reduction of China's energy-saving potential due to the popularity of the Internet. To enable the Internet to play its role and reduce its energy-saving potential, this paper proposes some policy implications.

Table 8. Heterogeneity analysis results.

variable	China	Eastern	Central	Western
L.ecp	0.434*** (39.44)	0.260** (2.05)	0.175 (1.48)	0.541*** (3.89)
int	-0.531*** (-16.75)	-1.215*** (-4.57)	-0.741*** (-4.26)	-0.142 (-0.49)
urban	0.013 (0.40)	0.600 (1.27)	-0.203 (-0.50)	0.445 (1.33)
od	0.038** (2.53)	0.152 (1.05)	1.708 (1.20)	-1.399* (1.75)
soe	-0.026*** (-3.71)	0.096 (1.50)	0.040 (0.21)	-0.033 (-0.37)
ip	-2.156*** (-12.77)	1.286 (0.52)	-6.523 (-0.99)	-11.901 (-1.23)
rd	-7.811*** (-42.24)	-16.723*** (-3.04)	-5.525* (-1.89)	-5.932*** (-2.65)
AR1	-1.27 [0.203]	-0.25 [0.823]	-0.47 [0.641]	-0.71 [0.480]
AR2	1.57 [0.117]	1.51 [0.132]	1.03 [0.303]	1.12 [0.261]
Hansen	28.68 [0.154]	2.48 [1.00]	3.58 [0.995]	7.50 [0.874]
Wald test	76639.42***	1869.50***	229.43***	144.35***
N	360	132	96	132

*Note: * p < 0.1, ** p < 0.05, *** p < 0.01.*

(1) The government should increase financial support for energy conservation in economically backward regions. This is conducive to achieving emission reduction targets in the western region and promoting sustainable development. First, it is necessary to strengthen environmental governance in the western region. Pollution control requires long-term, large-scale capital investment. However, the central financial transfer payment is difficult to meet the continuous capital demand. Special funds for environmental protection can effectively ensure the orderly development of environmental governance in the western region. Second, preferential policies related to energy conservation and consumption reduction should be introduced. The government should give certain tax breaks, subsidies, and credit incentives to low-polluting enterprises. This can stimulate the enthusiasm of enterprises in the western region for green production.

(2) The government should improve the coverage of Internet infrastructure. The application of big data depends on the establishment of new infrastructures, such as high-technology equipment. The government should speed up the construction of new infrastructure, such as the Internet and other network facilities and promote the interconnection of broadband networks between urban and rural areas. Moreover, it is also necessary to improve the service quality of broadband networks and the speed and efficiency of information transmission. This creates favorable conditions for the Internet to better exert its environmental welfare effect.

Notably, this study mainly focuses on the provincial and regional level and does not involve micro-survey data or enterprise micro-data. This is mainly because the data of micro-subjects in the use of the Internet has been difficult to obtain for a while. With the continuous improvement of micro data, the impact and micro-mechanism of digitalization on corporate emission reduction deserve attention. Although this paper establishes the Internet index system, it is not comprehensive enough. Therefore, future scholars can further enrich the Internet index and accurately reflect the internet level.

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Declaration of Competing Interest

All the authors claim that the manuscript is completely original. The authors also declare no conflict of interest.

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