Ambitious but deficient: Technology innovation route of China's energy industry

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Abstract

Energy industry is a vital area related to the security and economic development of a sovereign country, and the green and low carbon development is becoming the main development direction of global energy technology innovation (ETI). Driven by the energy revolution and the digital revolution, a new round of global technological revolution and industrial transformation is in the ascendant. China is constantly promoting ETI and actively exploring the factors affecting energy innovation efficiency in order to achieve the commitment of "carbon peak" and "carbon neutral". China's ETI still has shortcomings that are expected to break through. Using the province-level data of key variables in the field of ETI from 2008 to 2019, we found the stock of human capital, income level, carbon emission, industrial structure and the financial expenditure on science and technology may influence the energy innovation efficiency. The main reason of the energy innovation efficiency is the stock of human capital. And China is catching up with developed countries in the scale of its talent team with its consistently efforts. The increase of carbon emissions has a significant positive correlation with energy innovation efficiency at the national level while there is a negative correlation between carbon emissions and energy innovation efficiency in eastern China. Although China has formulated an ambitious five-year plan in the field of ETI, the basic research and human capital required to improve the efficiency of energy innovation are still shortcomings. Furthermore, state-owned enterprises and private enterprises cannot jointly build an innovation consortium has significantly restricted the efficiency of China's ETI. Due to the lack of unified coordination at the national level, there is vicious competition and prominent industry similarities in new energy between provinces The road to progress in China's energy technology innovation is still quite long.

Keywords: energy industry; ETI; human capital stock; "carbon peak" and "carbon neutral"

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I. INTRODUCTION

A healthy planet is an essential requirement and key enabler for sustainable development in which environmental, economic, and social objectives are addressed in a balanced manner through an integrated approach. According to the Medium Term Strategy for UNEP 2022-2025 entitled "For people and planet: the United Nations Environment Programme strategy for 2022–2025 to tackle climate change, loss of nature and pollution", the COVID-19 pandemic is more than a health crisis: it is also a humanitarian and socioeconomic crisis. It has exposed and aggravated vulnerabilities and inequalities and it is exacerbating already existing challenges in meeting the Sustainable Development Goals (SDGs) worldwide. The demand for economic growth and the growing global population have tripled the extraction of natural resources worldwide to destructive levels [1]. Climate warming, over-exploitation of resources, and loss of biodiversity have made energy a key area of concern for the security and development of a sovereign country. Since the outbreak of the Russian-Ukrainian war, global energy prices have continued to rise, posing a huge threat to global economic growth. The stability, diversity and low cost of energy supply have become an important political issue that have to reconsider by government. Green and low-carbon development has attracted more attention around the world. Renewable energy alternative technologies, electric vehicle technologies, natural gas hydrogen production technologies, and new power systems, safe and efficient nuclear energy technology is becoming the main development direction of global energy technology innovation.

Driven by the energy revolution and the digital revolution, a new round of global technology revolution and industry transformation is in the ascendant. So far, more than 130 countries/regions around the world have proposed zero emission targets [2]. ETI is considered one of the best pathways to transition to a global clean energy system and can play a vital facilitation role in global action to reduce carbon emissions. In 2021, the European Union, the United Kingdom, the United States, Russia, Japan, South Korea, and China have successively issued action policies for carbon peaking and carbon neutrality. On January 29, 2022, China's National Development and Reform Commission (CNDRC) and National Energy Administration (NEA) jointly issued the "14th Five-Year Plan for Modern Energy System". China is about to lead energy development based on technology innovation and insist on taking innovation as the primary driving force for development. The "14th Five-Year Plan" emphasizes that ETI will be developed around five aspects: advanced renewable energy, new power systems, safe and efficient nuclear energy, green and efficient fossil energy development and utilization, and energy digitalization and intelligence. China has formulated an ambitious technology innovation roadmap for this purpose. It aims to anchor carbon peaking and carbon neutrality, accelerate the transformation of the energy structure, improve the efficiency of the energy system, achieve a high-quality jump in energy, achieve an innovation-driven development strategy, improve the level of innovative human capital, and promote the digitalization and intelligence of the energy industry and energy The modernization of the industrial chain has continuously injected new momentum into promoting high-quality economic development and building a modern country.

Although ETI has been emphasized by many countries, it is not easy to achieve. Since persistent investment of R&D does not necessarily bring about great progress in the field of ETI, the efficiency of energy innovation must be considered. Energy innovation efficiency (EIE) is a performance measurement of energy innovation. In recent years, research on EIE and its influencing factors has become a research hotspot in academia. A basic premise is how to measure it. Judging from the literature review, the academic community has not reached a consensus standard. At present, the mainstream measurement methods mainly include nonparametric methods including Data Envelopment Analysis (DEA) [3][4][5][6]. The number of patents applied and granted to measure innovation input and output efficiency [7][8]. When trying to measure green EIE by building a model, it is considered feasible to build a DEA model through a two-stage innovation value chain, which has been applied in a study of technology innovation efficiency of industry enterprises in 31 provinces in China [9]. DEA has been used to evaluate the effect of innovation-driven policies in related research of new energy vehicles, such as measuring the innovation efficiency of Chinese new energy vehicle listed companies from 2015 to 2017.

The number of national patent applications can also be used as a measure of the efficiency of technology innovation. The number of green patents as a measure of the field of energy innovation has a great fit. For example, the results of an empirical study on 79 countries' panel data from 1995 to 2017 show that renewable energy and energy efficiency boost innovation performance at aggregate and disaggregated levels [10]. Deng and Liao (2009) believe that the measure of technology innovation can also be replaced by the number of patents applied or granted [11]. For example, the innovation of renewable energy can be replaced by the number of patents applied or granted by using the negative binomial distribution. Based on this, it is a meaningful exploration that green patents can be used to measure the efficiency of energy innovation.

It is well known that human capital is an indispensable factor in driving a country to achieve innovation. The empirical analysis based on the Heterogeneous Stochastic Frontier Model (HSFM) shows that human capital stock has a significant role in promoting regional innovation efficiency, and the improvement of human capital level can enhance the stability of regional innovation efficiency [12], high school, undergraduate and graduate students, etc. The increase of human capital at the educational level can promote the improvement of regional innovation efficiency [13]. Of course, the factors affecting ETI are extremely complex. The positive impact of per capita income level on ETI is a prominent example. Fagerberg & Srholec's (2007) empirical analysis of 115 countries during the period 1992-2004 shows that the innovation efficiency system is highly positively correlated with per capita income levels[14]. Yang and Yao (2018) believe that if the income of an industry is increased, the enthusiasm of laborers to innovate can be ignited, thereby improving the innovation efficiency of the industry[15]. Based on the above analysis, it is believable that the higher the per capita income of the region, the higher the enthusiasm of the laborers, and the higher the efficiency of ETI. Another factor affecting ETI is closely related to carbon emission constraints. An analysis of the correlation between energy consumption carbon emissions and green innovation efficiency in China's equipment manufacturing industry found that coal and crude oil carbon emissions have a positive impact on green innovation efficiency [16].

The existing research mainly focus on measuring energy innovation efficiency with DEA model, and there are few literatures on energy innovation performance with green energy patent application as the measurement criterion; Scholars have paid attention to the inhibitory effect of income distribution gap on innovation efficiency [17]. However, there are still deficiencies in the research on improving the income level of the whole industry and improving the efficiency of energy innovation with the help of economic growth and labor productivity. At the same time, although many studies have focused on the impact of technological innovation on carbon emission reduction, there are relatively few related studies on how carbon emissions affect energy technological innovation. At present, technological innovation has become the main battlefield in the game of great powers, and the scale of innovative human capital has a profound impact on the improvement of national innovation efficiency. If a country wants to expand the scale of innovative human capital, it must strive to improve the quality of innovative human capital and create more world-class scientific and technological leaders and innovative teams. Only in this way can it be possible to achieve key energy innovation results, improve the efficiency of energy innovation, and obtain long-term competitive advantages.

This paper takes the number of green patent applications by residents of 31 provinces in China from 2008 to 2019 as the core explanatory variable to measure the efficiency of energy technology innovation. In order to discuss the development prospects of China's ETI efficiency, the article measured the human capital stock, income level and carbon emission reduction level respectively, and verified the impact of human capital stock, income level and carbon emission on the efficiency of China's ETI by constructing an empirical analysis.

II. CHINA AMBITIOUSLY BUILDS ROADMAP FOR FUTURE ENERGY TECHNOLOGY INNOVATION

China is a country that lacks oil and gas among the world's major powers. Its dependence on foreign oil is as high as 70 percent, and there is limited room for increasing production in the future. Developing renewable energy and attaching importance to energy technology innovation is an indispensable development direction to resolve China's energy security. After the outbreak of the Russian-Ukrainian war, China had to formulate more aggressive new energy development goals, vigorously promote the large-scale, high-proportion, high-quality, and market-oriented development of renewable energy, try to improve new energy consumption and storage capabilities, and actively build renewable energy. A new power system with new energy as the main body, improve the institutional mechanism and policy system that is conducive to the joint development and utilization of renewable energy by the whole society, and provide a strong guarantee for the construction of a clean, low-carbon, safe and efficient energy system. And based on the clean energy system, guide the industry to develop in the direction of low energy consumption and high technology, and gradually reduce the proportion of oil in the industrial economy [18].

$755 billion has been spent on deploying low-carbon energy technologies around the world since 2021, with nearly half of that investment taking place in Asia. China has invested US$266 billion in energy transition, accounting for 35 percent of the total global investment in the first place [19]. Since 2008, China's investment in traditional energy supply industries such as electricity, heat and gas has gradually slowed down. The output of clean resources such as natural gas, nuclear power, and wind energy continues to rise, and the proportion of clean energy in the energy structure continues to increase. For example, the proportion of raw coal production has dropped by 9.2 percent in ten years, and the proportion of total crude oil production has dropped by 2.5 percent in ten years[20]. These are all China's efforts to continue to adhere to the energy demand-oriented, give full play to the advantages of the domestic large-scale market, focus on solving the core technical problems of energy, and speed up energy conservation and emission reduction. It is hoped to achieve carbon peak by 2030 and carbon neutrality by 2060, which reflects China's ambitious strategic deployment on the road of ETI.

According to World Energy Investment 2021 by IEA, under the influence of the COVID-19 pandemic, enterprises in 2020 reduced their expenditure on energy research and development in the private sector due to the reduction of budgets. But annual global energy investment rises to US$1.9 trillion by 2021, rebounding nearly 10 percent from 2020, bringing total investment back to pre-pandemic levels. Meanwhile, its investment structure has shifted towards the power and end-use sectors, rather than traditional fuel production [21]. Therefore, the background of the times has put forward higher requirements for the functions of the government - the government should play the role of formulating policies and regulations, emphasize the innovative role of the economy, and continue to promote the zero-emission policy. For example, in terms of traditional fuel energy, CNDRC issued the "Guiding Opinions on Accelerating the Intelligent Development of Coal Mine “on February 25, 2020. Demonstrate coal mines, give priority support in terms of capacity replacement and mine capacity increase, and introduce relevant industrial support policies to encourage financial institutions to increase support for intelligent coal mines. The Ministry of Finance has also issued relevant inclusive preferential policies. In addition to the tax reduction and exemption policies for general high-tech enterprises, such as levying corporate income tax at a reduced rate of 15 percent for recognized high-tech enterprises, there are also tax reduction and exemption policies for enterprises that meet the requirements for environmental protection and energy conservation. 10 percent of the investment in special equipment such as water saving and safe production can be deducted from the tax payable in the current year; these preferential policies are available to qualified coal enterprises, aiming to encourage coal enterprises to speed up intelligent mining.

Therefore, China has also made breakthrough achievements in energy conservation and emission reduction in recent years. In terms of scale, in 2022, the annual power generation of China's new energy facilities will exceed 1 trillion kWh for the first time, the total annual power generation of China's photovoltaic power generation will reach 350 billion kWh, and the annual total power generation of wind power will exceed 400 billion kWh. It ranks first in the world at present; it has also made great achievements in new energy facility technology, such as independent development, including the strongest offshore wind turbine in Asia-Pacific with a single installed capacity of 10 megawatts, and Baihe, whose installed capacity ranks second in the world. Tan Hydropower Station and other advanced new energy power generation equipment. China will continue to promote green and low-carbon development, while strengthening cooperation with overseas countries, aiming to jointly build a community with a shared future for mankind.

At the same time, with the transformation and upgrading of China's energy structure, the global energy supply and demand structure has changed. Higher requirements are put forward for the improvement of energy innovation efficiency. China needs to identify the paths that affect the efficiency of energy innovation, continuously improve its comprehensive strength, broaden the channels for improving the overall efficiency of energy innovation, absorb funds from various aspects, and encourage domestic and foreign companies to invest in clean energy. investment, and actively absorb international capital and private capital. According to Sohu.com, we used web crawler technology to extract 297 pieces of text information about "energy technology innovation", with a total of about 118,000 words. We used R (4.2.0) software to perform word segmentation and word frequency statistics to extract keywords with a word frequency greater than 50. A total of 113, draw a word cloud map (Figure 1). It can be seen that “technology”, “innovation”, “development” and “greenness” have not only become the hotspots of China's large-scale Internet portals, but also the hotspots of capital investment. China has successfully created a fabulous landscape in the whole society that attaches importance to technology innovation and to promote the transformation of energy utilization.

III. RESEARCH METHODS AND RESEARCH DATA

A. Research Methods

Considering that many scholars usually use a two-way fixed effect analysis model when analyzing green ecological efficiency and green economic efficiency[22], this research method is also used to eliminate the estimation error in traditional statistical models. To ensure the availability and comparability of research data, panel data of 31 provinces from 2008 to 2019 is used to measure the influencing factors of China's energy innovation efficiency in this paper. The relevant data come from the China Statistical Yearbook and the State Intellectual Property Office.

Figure 1. A word cloud map of China's ETI

To explore the effect of human capital on the efficiency of energy innovation, we select the number of green patent applications in each province as a proxy variable to measure the level of energy innovation. Gross wages measure human capital stock and provincial per capita income, respectively.

The industry upgrading coefficient mentioned by (Xu and Jiang (2015) is used to measure the industrial structure upgrading level of each province[23]:

$$IS = \sum_{i=1}^{3} q_i \times i = q_1 \times 1 + q_2 \times 2 + q_3 \times 3$$

Among them, q_i is the proportion of the output value of the i-th industry, and the data comes from the China Statistical Yearbook (CSY).

Fiscal science and technology expenditures are the expenditures made by the government and its related departments to support technology activities. It refers to the scientific research expenditures arranged in the national financial budget. The data comes from the CSY. In view of the large number of green patent applications, the average number of students in colleges and universities, and the salary of the employed population, this study carried out a regression empirical study after logarithmic operation. The calculation model is as follows:

$$lngreenpatent = \beta_0 + \beta_1 lnhc + \beta_2 wage + \beta_3 carbon + \beta_4 lnd + \beta_5 fin + \lambda_t + \mu_i + \varepsilon_{it}$$

Among them, β_0 is the intercept term, β_i（$i = 1,2\ldots5$）represents the coefficient parameter corresponding to each explanatory variable, λ_t is the time effect that does not change with the individual, μ_i is the individual effect that does not change with time, and ε_{it} represents random error term..

B. RESEARCH RESULTS

B.1 Descriptive Statistical Analysis

As shown in Table 1, the main variable names, mean, standard deviation, minimum and maximum values are listed. Tibet was excluded from the study due to missing data on Tibet. Through descriptive statistical analysis, the number of energy green patent applications in China and the level of wages fluctuate greatly, indicating that there is a large gap from energy patent applications to income in provincial level (Figure 2). China's industry upgrading coefficient has little difference between 30 provinces.

Table 1. Descriptive Statistics for Primary Variables

VARIABLES	N	Mean	Sd	Min	Max
Gp	360	6,180	9,836	31	67,258
Hc	360	2,518	888.1	969	6,750
Wage	360	3,068	2,960	140.4	20,510
Fin	360	0.438	0.257	0.153	1.368
Carbon	360	162.3	119.3	2.208	628.6
Ind	360	2.369	0.127	2.132	2.834

B.2 Regression Analysis

A multicollinearity test was performed before regression analysis of the study data. If the VIF index is less than 10, there is no need to eliminate the corresponding explanatory variables, and the model fits well.

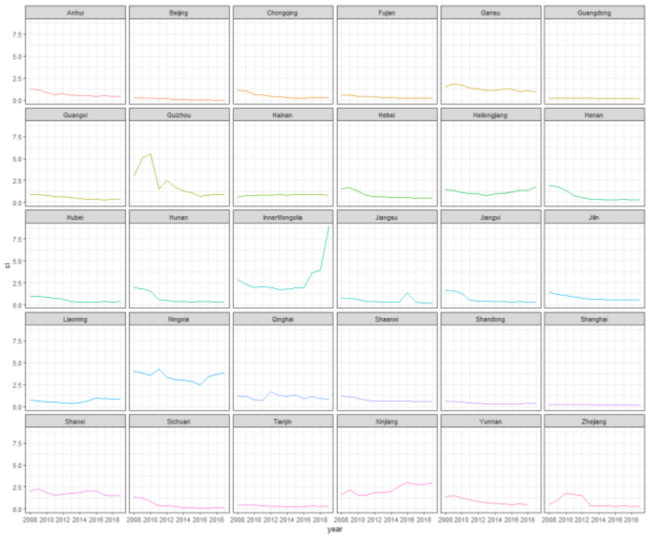

Figure 2. Inter-provincial differences in the number of green energy patent applications

Panel data supported fixed effects by Hausman test. Table 2 reports the regression results for the mixed regression model, the fixed-effects model, and the two-way fixed-effects model. With the addition of individual fixed effects and two-way fixed effects, the goodness of fit R^2 of the model increased from 92.2 percent to 96.2 percent, indicating that the two-way fixed-effects model had a good fitting effect.

Table 2. Test for Multicollinearity

Variable	VIF	1/VIF
Ind	3.810	0.262
Fin	2.860	0.349
Hc	2.140	0.468
Wage	1.910	0.523
Carbon	1.440	0.697
Mean VIF	2.430	—

Firstly, EIE and human capital stock are regressed. As shown in Figure 3, there is a significant positive correlation between energy innovation efficiency and human capital stock. Secondly, Table 3 reports the results of influencing factors. For human capital stock and national financial investment in science and technology, first, an individual fixed effect model is introduced into the regression of human capital stock, and the coefficient increases from 0.563 to 1.028, indicating that OLS underestimates the impact of human capital stock on green energy innovation efficiency. influence. However, after the introduction of the two-way fixed effect, its coefficient has dropped to a certain extent, indicating that the individual fixed effect overestimates the impact of human capital stock on the efficiency of green energy innovation. But overall, whether it is an OLS or a two-way fixed-effect model, the human capital stock has a positive impact on the efficiency of green energy innovation; secondly, the more the state finances invest in science and technology education, the higher the country's energy innovation efficiency. The side shows that the increase of investment in science and technology education and the growth of human capital stock also complement each other. Since the 19th National Congress of the Communist Party of China, China's talent team expansion scale has continued to catch up with developed countries, and it is at the breaking point of qualitative change in the cultivation of world-class talents and the creation of output. The strategy of strengthening the country with talents is the source of living water for China's energy innovation efficiency.

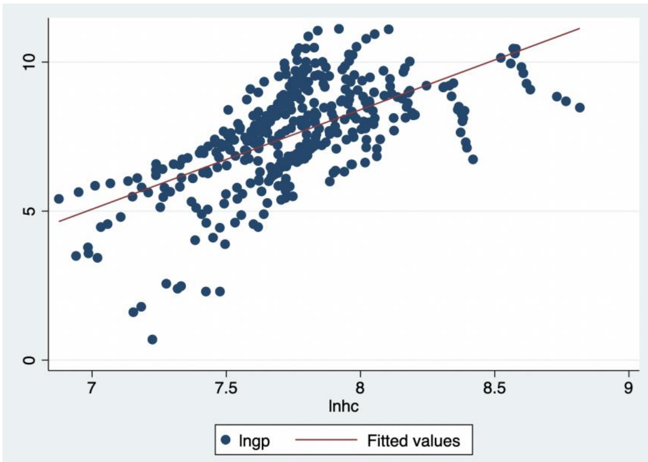

Figure 3. Scatter plot of green innovation efficiency and human capital stock

Regarding the income of Chinese residents, based on the same sample, its significance weakens with the gradual introduction of individual fixed effects and two-way fixed effects, indicating that the impact of wage levels on innovation efficiency is overestimated. It also shows that income is less important to the efficiency of energy innovation than the stock of human capital. However, it is undeniable that the level of income does affect the level of domestic ETI. When residents' income continues to increase, their knowledge-based investment in themselves increases, and the quality of workers continues to improve. Then, under the guidance of the country's active innovation, residents are more willing to participate in innovation work, and the stronger the innovation capability in the region, which will improve the efficiency of energy innovation. To a certain extent, raising the national wage level by the state has a certain positive effect on energy innovation, but its effect is not as large as the stock of human capital. Therefore, when formulating national policies, China focuses on guiding and cultivating more innovative talents.

Table 3. Influencing Factor Regression Results

	(1)	(2)	(3)
VARIABLES	lngp	lngp	lngp
Lnhc	0.563***	1.028***	0.921***
	(5.72)	(6.65)	(7.88)
Lnwage	1.445***	1.002***	0.203*
	(40.79)	(16.62)	(1.78)
Fin	0.204	0.641***	0.667***
	(1.41)	(4.70)	(6.48)
Crbon	-0.000	0.002***	0.001***
	(-1.08)	(3.82)	(3.00)
lnd	-0.053	4.051***	-0.830*
	(-0.16)	(9.56)	(-1.87)
Constant	-7.559***	-18.036***	-0.487
	(-9.79)	(-14.73)	(-0.32)
Observations	360	360	360
R-squared	0.922	0.928	0.962
Province FE	YES	YES	YES
Year FE	NO	NO	YES
Number of id		30	30

What deserves attention is the amount of carbon emissions and the level of industrial structure upgrading. The fundamental reason for China's high carbon emissions is that energy and its related industrial systems are largely dependent on fossil resources. China's power industry and high-energy-consuming industries (steel, petrochemical, cement, non-ferrous metals, etc.) carbon dioxide emissions account for about 80 percent of the country's total carbon dioxide emissions and are industries that need to be focused on. This study combines the economic theory hypothesis "Environmental Kuznets Curve" to illustrate. In terms of carbon emissions, carbon emissions and energy innovation efficiency first increase with the growth of per capita GDP. After the inflection point, carbon emissions and energy innovation efficiency decrease with the growth of per capita GDP. The empirical results show that, at the Chinese level, the increase in carbon emissions has a significant positive correlation with the improvement of energy innovation efficiency, indicating that China is actively promoting the green transformation of its economic structure and improving its energy innovation capabilities. China is constantly conducting comprehensive and revolutionary explorations and adjustments, aiming to make China's high-quality development goals compatible with global climate governance goals.

In descriptive statistics, China has almost kept pace in upgrading its industrial structure across regions, so it is unreliable to only do individual fixed-effect results. For decades, China has continuously promoted the optimization and upgrading of the energy industry structure, promoted the green and low-carbon transformation of traditional high-energy-consuming industries, and vigorously developed green and low-carbon industries. However, empirical results show that energy innovation efficiency is negatively correlated with industrial upgrading. Based on this, this research tentatively believes that although China's energy technology has made great progress, the way of upgrading the industrial structure is still unscientific and the driving force for innovation efficiency is insufficient. Therefore, to achieve the "dual carbon" goal, China It is not only necessary to break through many key technologies in various fields, but also to break the barriers between various energy types and energy-related industries, to break through the key bottlenecks and core technologies of multi-energy integration and complementarity and industrial process reengineering in related key industries, especially to overcome related industries. Difficulties in industrial transformation and upgrading. For example, while adjusting the industrial structure and carrying out industrial transfer, scientifically plan the direction of industrial transfer and adjustment, take the market and products as the guide, eliminate backward and energy-intensive enterprises without blindly expanding the scale, so as to continuously strengthen the innovation of energy technology system and drive Efficient energy saving and emission reduction.

In order to further explore the influence factors of various factors on the efficiency of energy innovation, this study conducted a regional heterogeneity regression on the eastern, central and western regions of China (Table 4). Among them, according to the level of economic development classification. The eastern region of China includes 11 provinces including Beijing, Tianjin, Hebei, Shanghai, Jiangsu, Zhejiang, Fujian, Shandong, Guangdong, Hainan and Liaoning; the central region includes Shanxi, Anhui, Jiangxi, Henan, Hubei, Hunan, Jilin and Heilongjiang in 8 provinces in China; 12 provinces in the west, including Inner Mongolia, Guangxi, Chongqing, Sichuan, Guizhou, Yunnan, Tibet, Shaanxi, Gansu, Qinghai, Ningxia and Xinjiang(Because there is no data of Tibet, only 11 provinces were considered).

From the regression results shown in Table 4, the human capital stock in the eastern, central, and western regions of China, significantly affects the efficiency of energy innovation at the level of 1 percent, which indicates that the reserve of innovative talents has a decisive impact on energy innovation. Therefore, China needs to make greater breakthroughs in cultivating outstanding scientists and technology talents. Significantly improve the ability of independent innovation, promote the continuous improvement of energy efficiency, and realize the "dual carbon" goal as soon as possible.

Table 4. Regional Heterogeneity Regression Results

	(1)	(2)	(3)
	lngpEast	lngpMiddle	lngpWest
Lnhc	0.943***	1.548***	0.971***
	(4.67)	(4.34)	(3.50)
Lnwage	0.201	0.636**	-1.342***
	(1.54)	(2.59)	(-3.84)
Fin	0.568***	0.895***	0.088
	(4.37)	(3.86)	(0.34)
Carbon	-0.002*	0.001	-0.000
	(-1.83)	(1.27)	(-0.59)
Lnd	0.578	-2.214**	-1.083
	(0.77)	(-2.22)	(-1.39)
Constant	-2.954	-5.189*	9.177***
	(-1.20)	(-1.90)	(2.92)
Observations	132	96	132
R-squared	0.974	0.975	0.964
Number of id	11	8	11
Province FE	Yes	Yes	Yes
Year FE	Yes	Yes	Yes

Some scholars have studied the efficiency of green innovation among regions in China, and the empirical results show that there is a downward trend in the efficiency of green innovation in western China from 2006 to 2016[23][24]. The results of this study show that the income level in the western region has a negative impact on innovation efficiency at the 1% significance level. Therefore, the current energy problem in the economic development of western China is not only to ensure the sustainable income increase of low-income groups. While nominal wages across the country are rising steadily, the income distribution mechanism will be reformed, efforts will be made to narrow the income gap, and steady progress will be achieved in improving income and energy efficiency. The correlation between carbon emissions and EIE in eastern China is significantly negative. According to the Environmental Kuznets Curve, it can be speculated that the inflection point has already appeared first in eastern China. This shows that in order to realize the international commitment of carbon emission reduction, Chinese government has achieved optimistic achievements in the exploration of green and low-carbon transformation through continuous technology innovation.

IV. DEFICIENCIES THAT CHINA'S ENERGY TECHNOLOGY INNOVATION NEEDS TO BREAK THROUGH

Under the dual pressures of global warming and shortage of fossil fuels, reducing carbon emissions is not only required for China to fulfill its national commitment to reducing greenhouse gas emissions, but also a strategic choice for China's low-carbon and green development transition. It is worth noting that China's energy consumption is still very large, and it is urgent to break through the inherent deficiencies that restrict the efficiency of energy technology innovation to achieve the goal of carbon emissions. AS we all know, the indicator of carbon intensity is mainly used to measure the relationship between the national economy and carbon emissions. If a country's economic growth is accompanied by a decline in carbon dioxide emissions per unit of GDP, it means that the country has achieved a transition to low-carbon development. From the three-dimensional map of carbon intensity in China's provinces from 2008 to 2019 depicted in Figure 4, China has made continuous efforts for "carbon peaking" and "carbon neutrality". As an important goal of China's "14th Five-Year Plan" pollution prevention and control battle, the carbon emission intensity of China's provinces has shown a long-term downward trend for more than ten years. Therefore, China's carbon emission intensity has made positive progress.

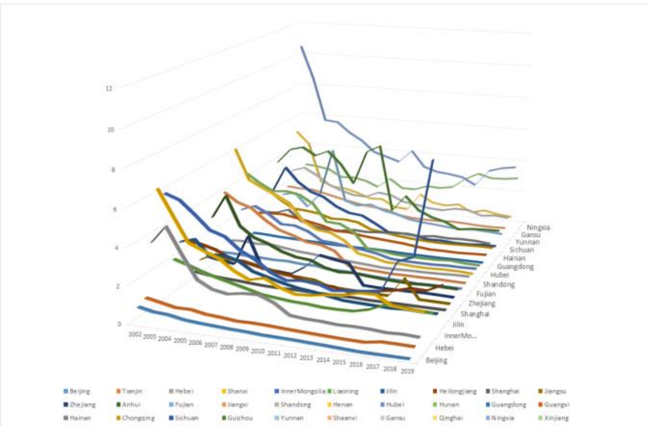

Figure 4. Carbon intensity map by province in China:2008-2019

Nonetheless, the empirical results of this study significantly suggest that energy technology innovation is driven by talent stock. due to the lack of unified coordination at the national level, there is vicious competition and prominent industrial similarities in the development of new energy between provinces, insufficient investment in basic research, lack of agglomeration effect and scale effect for talents of ETI, and state-owned enterprises and private enterprises cannot jointly build an innovation consortium has significantly restricted the efficiency of China's ETI.

In order to realize its ambitious energy technology innovation plan, it is necessary to take effective measures to overcome the shortcomings of development. Firsly, to improve the efficiency of energy innovation, under the ambitious energy innovation plan, it is still indispensable that China must continuously increase the importance of talents from the demand side and increased the intensity of investment promotion. Secondly, although China's industrial structure is not very different, for some provinces with large energy supply, China is constantly strengthening energy supply and demand adjustment, improving energy supply security capabilities, continuously promoting the optimization, and upgrading of industrial structure, and increasing a series of policies such as forest carbon sinks. Measures to improve green total factor productivity; Thirdly, since China has promoted the carbon peaking action, it has continuously promoted the implementation of the carbon peaking and carbon neutral "1N" policy system and promoted the construction of an economic system with green, low-carbon and circular development.

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