Investigations on the relation between China's increasing renewable energy power generation and economic expansion

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Abstract. This study is intended to investigate the relation of China's economy expansion and renewable energy output. Expressing electricity production using renewable resources as the growth rate of renewable energy electricity output by category and the growth rate of renewable energy share, while denoting economic growth as GDP growth rate and electricity consumption per unit of GDP, the research examined the panel data from 2002 to 2020 with OLS model, and the robustness tests and heterogeneity analysis were completed. Research finds that China's renewable energy generation growth has a two-way relationship with economic growth. For heterogeneity analysis, the panel data of province GDP growth and electricity generation growth rates were used. The findings suggest that the classification criteria for provinces or the control factors that affect the findings need to be improved and taken into account. The finding shows that under the precondition that developing countries' rising energy usage benefits their economies' progress, optimizing the energy structure and promoting green transformation and sustainable development will both temporarily and permanently aid in the economy's development.

Keywords: Economic growth, Renewable energy, China, Electricity production.

1. Introduction

The formation of fossil fuels forces people to deal with the drawbacks of fossil energy in their growth: scarcity, non-renewability, and risks to the environment and climate. Nevertheless, the process of a country's economic growth and social advancement depends heavily on fossil fuels. The Sustainable Development Agenda for 2030, which contains the objective for sustainable consumption and production patterns, was endorsed by the UN at the Summit on Sustainable Development [1]. This implies that when it comes to the issues brought on by fossil fuels, both developed nations with significant wealth and emerging nations on the path to prosperity are in the same situation. Environmental concerns, climate change issues, and energy supply inconsistencies brought on by a nation's heavy reliance on fossil fuels would unavoidably have a detrimental impact on that nation's economic development. Therefore, research on renewable energy and its effects will provide theoretical solutions to the issues of stimulating economic growth, preserving sustainable development, and expanding job possibilities under the green economy model.

China is significant for the study of how to achieve sustainable economic growth since it has the biggest scale of renewable energy production and consumption globally [2]. To investigate the development of new energy and analyse its link with GDP, this study uses the growth rates of various forms of renewable energy electricity production in China as well as the growth rates of electricity output from renewable sources as indicators. The study's findings can present the relation of the power production using fossil and renewable energy and economy expansion, and the extent of each impact on growth in the economy. Throughout this section, the paper shows how influential each is in the process of economic growth. These results can theoretically support the development of new energy sources for electricity production.

This essay's remaining sections are organized as follows. A summary of China's energy situation is given in Section 2. The literature on new energy and economic growth is summarized in Section 3. Potential hypotheses are presented in Section 4. Section 5 contains information on the research's data, methodology, steps, and outcomes. Section 6 presents the findings and study limitations.

2. Overview of current energy production status in China

As can be seen from figure 1, China's use of renewable energy is rapidly growing, its proportion is rising, and its energy structure is being optimised on the production side. Different patterns may be seen in the share of various energy sources during the last ten years. In 2021 compared to 2012, the percentage of raw coal output was 8.6 percentage points lower. Additionally, the percentage of crude oil output decreased from 8.5 to 6.6 percentage points. Two percentage points higher natural gas was used overall, which is a minor rise. With an increase of 8.5 percentage points in 10 years, the proportion of primary energy production, including wind, nuclear, and hydroelectric, has expanded dramatically. However, despite the fact that coal's share is still decreasing, it will be China's main source of energy for a considerable time.

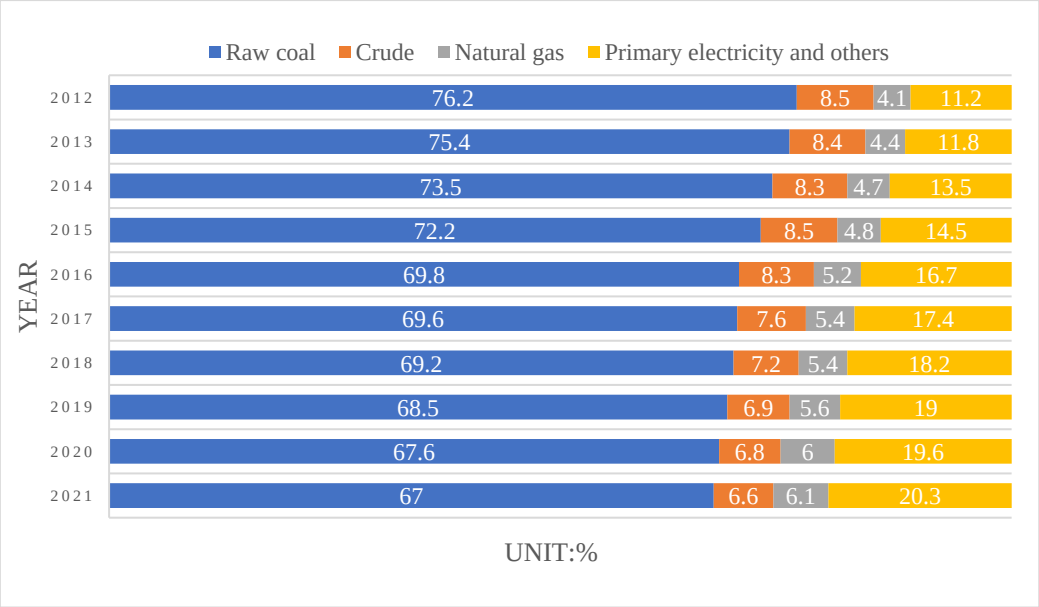

Figure 1: China's Energy Structure 2012-2021

Data source from: China Statistical Yearbook

3. Literature Review

Energy and economic development have been hotly debated during the last few decades. Regarding their relationship, there are various points of view. In summary, four categories can be used to group these viewpoints. The idea that energy usage has a considerable impact on the economy expansion falls under the first group. In this case, energy has a unilateral effect on economy expansion, which means that efforts to save energy hinder economy expansion. The second type of conclusion claims that rising economic expansion also raises the need for energy. Under this circumstance, energy-saving strategies do not have any influence on economy expansion. The third kind is the symbiotic relationship between economic expansion and energy, which implies that any modifications to one will have an impact on the other. The lack of any connection between energy consumption and economy expansion is the fourth conclusion. The two are distinct and do not affect one another. The following is a list of connected literature.

Sadosky concluded by investigating panel data on consumption of renewable energy and income in developing nations. He noticed that when actual per capita income grows, consequently does the usage of renewable energy [3]. Fang discovered that when the share of renewable energy increased in China, socioeconomic welfare also climbed [4]. Cho, Heo, and Kim reviewed data from advanced and developing countries and observed discrepancies in the link between energy usage and economic development. Energy usage continues ascending in industrialized countries due to rising GDP, while GDP and consumption of energy have a two-way causal link for underdeveloped nations [5]. Menegaki used the random effect model to evaluate the connection in the use of GDP and renewables

in European nations, however the results showed that the connection was either weak or perhaps nonexistent [6].

Specifically speaking, however, regarding how renewable energy contributes to sustainable economic growth, little evidence is available, which indicates that this topic is a new branch of the ones mentioned above and has a lot of study potential. Due to relatively backward conditions such as infrastructure, unequal distribution of resources, scarce statistical data, and various influencing factors, renewable energy have comparatively fewer researches on it. In recent years, a lot of researchers examined the connection in economy expansion and energy use. According to Wolde-Rufael, labour and capital contribute much more to economic growth than energy in 17 African nations [7]. Costantini and Martini's report claims that economic expansion contributes to short-term energy usage, while having a two-way causal relationship in the long term [8]. Bhattacharya, Rafiq, and Bhattacharya found that under current energy model, increasing energy efficiency has a significant impact on coal use and sustainable development [9]. The research about the connection between traditional fossil fuels and economic growth have been greatly enriched by these studies.

4. Hypotheses

Since the connection in energy and economy expansion is not fixed, as was stated in the literature study, the hypotheses of this research also take into account these four dimensions. According to the first hypothesis, the growth of the nation's economy is promoted by increased production of electricity from renewable sources. The share of new energy is steadily rising, and China's energy structure is constantly improving, according to the current status of renewable energy in China. This opens up opportunities for the national economy's sustainable growth and green transformation.

The second hypothesis holds that the status of the national economy affects the growth of new energy power generation. Since the start of the twenty-first century, the utilization of renewables has been planned for by the Chinese government. It can be inferred that China is making significant investments in the new energy sector from the "Implementation Plan for Promoting High-Quality Development in the New Era" [10] issued by the National Energy Administration of China in 2022. This is another key factor in the expansion of the production of new energy.

The third hypothesis is that the nation's economy and the production of new energy power are causally related in both directions. Coal and thermal power generation now dominate China's energy structure, and this situation is not likely to alter very soon. The current situation should therefore be considered while researching the connection in economy and energy development. The last theory supports the neutral hypothesis, which maintains that there is no connection between the two.

5. Methodology, data, and results

5.1. Model and data selection

The relation between the generation of power from renewable sources and economy expansion was modelled using an equation.

$$Y = f(x_{hyd} + x_{nuc} + x_{win} + x_{the})$$

Y stands for economic development, whereas x_{hyd}, x_{nuc}, x_{win},and x_{the} stands for the expansion of hydropower, nuclear, wind, and thermal generation. To ensure the reliability of the model, the research applied different variables to depict the explanatory variable (renewable energy growth) and the dependent variable (economic growth).

One set of explanatory factors among them is the growth rate of power generation for each form of energy, and another set is the percentage of power generation from renewable sources. This is because, although annual increases in power production, not all energy sources contribute equally to this process. Simultaneously, whereas total power generation immediately reflects the state of the

economy, the fraction of renewable energy power generation could more effectively demonstrate changes in the energy structure.

For the dependent variable, two measurements of variable were chosen. The first is GDP growth, one of the most popular indicators of economic progress. The other is the amount of power used per unit of GDP ($\frac{Electricity\ consumption\ of\ the\ whole\ society}{GDP}$). The rationale behind choosing this variable is that an increase in power generation will influence its value even if its numerator and denominator remain the same. This contributes to the internal logic of power generation's relationship to economic growth and productivity.

In terms of data sources, data about power generation from various energy sources and total societal electricity consumption are provided by China's National Bureau of Statistics. GDP growth rates are taken from the World Bank database. By computing the logarithm and then taking the first-order difference from the original data, power generating growth rates and the proportion of renewable energy electricity production are measured. The original data from the China's National Bureau of Statistics is also used to value the quantity of electricity used per unit of GDP. Due to the absence of renewable energy data during the previous two years, this paper only selects the data from 2002 to 2020 as the analysis sample. The data were analysed using the statistical software STATA.

5.2. Descriptive statistics for the variables

Table 1 illustrates the correlations among the variables in the panel dataset. Each variable in Table 1 has a name explanation in Table 2. Following China's energy structure, which is dominated by thermal power, Table 1 demonstrates that thermal power has the highest link with economic growth. Wind power generation has a slightly weaker link, yet this may be confirmed by China's robust increase in wind power generation in 2010. For nuclear power generation, the result is not significant because it accounts for a smaller percentage of total energy production than other renewable energy sources. Hydropower generation is mainly restricted by the principle of hydropower generation and China's relevant policies. Although hydropower occupies a leading position in China's new energy power generation, due to its use of natural hydrological phenomena to obtain electricity, its output cannot be obtained by increasing input to a certain extent. Meanwhile, since thermal power is associated with coal and other industries, the expansion of hydropower development will inevitably cause damage to these industries. Therefore, the phenomenon that the amount of discarded power is much higher than the actual grid power often occurs. This explains the insignificant relationship between hydropower growth and economic growth.

Table 1: Pairwise correlations of variables

Variables	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
(1) dlogava	1.000								
(2) dlogpro	1.000***	1.000							
(3) dloghyd	0.087	0.087	1.000						
(4) dlognuc	0.070	0.068	-0.381	1.000					
(5) dlogwin	0.726**	0.724**	-0.197	-0.120	1.000				
(6) dlogthe	0.972***	0.971***	-0.134	0.115	0.746**	1.000			
(7) dr_sav	-0.681**	-0.684**	0.883***	0.126	-0.472	-0.845***	1.000		
(8) con	0.803***	0.802***	0.288	0.116	0.738**	0.754***	-0.011	1.000	
(9) rgdp	0.763***	0.766***	0.276	-0.075	0.654**	0.718***	-0.168	0.767***	1.000

*** p<0.01, ** p<0.05, * p<0.1
Variable (1)-(7) are calculated using natural logarithms

Table 2: Explanation of variable names and calculation

(1)	Electricity Availability Growth Rate	Calculate the logarithm from the original data and then perform the first-order difference
(2)	Electricity Production Growth Rate	
(3)	Growth rate of electricity produced by hydropower	
(4)	Growth rate of electricity produced by nuclear power	
(5)	Growth rate of wind power production	
(6)	Growth rate of thermal power production	
(7)	Growth rate of renewable energy generation share	
(8)	GDP growth rate	
(9)	Electricity consumption per unit of GDP	$\frac{Electricity\ consumption\ of\ the\ whole\ society}{GDP}$

5.3. Processing steps and results

Ordinary least squares (OLS) and regression analysis methods are applied to evaluate the relation in the development of renewables and economy expansion.

The first step is the regression analysis of the growth rate of hydropower production and electricity consumption per unit of GDP. Table 3 displays the outcomes of the analysis. Regression is performed to observe the relationship between different renewables and economy expansion, by using the growth rate of thermal power output as a control variable.

At the 5 percent level of statistical significance, every coefficient is positive and statistically significant. Referring to variable 8's original meaning (electricity consumption per unit of GDP), it can be found that when GDP is considered unchanged, the increase in power generation will lead to an increase in electricity consumption in the whole society. In fact, GDP is also increasing. As Xie, Bai, and Cong found, income growth and energy consumption are correlated positively linearly. [11]. Therefore, power generation leads to an increase in electricity consumption and thus promotes economic development. Concurrently, the coefficient of thermal power in this study is larger than that of hydropower, which shows that the weight of thermal power and the coal industry in China is still greater than that of hydropower.

Table 3: The regression relationship between dloghyd and con

Source	SS	df	MS	Number of obs	= 18	
Model	0.005915876	2	0.002957938	F(2, 15)	= 19.57	
				Prob > F	= 0.0001	
Residual	0.002266722	15	0.000151115	R-squared	= 0.7230	
				Adj R-squared	= 0.6860	
Total	0.008182599	17	0.000481329	Root MSE	= .01229	
con	Coefficient	Std. err.	t	P>|t|	[95% conf.	interval]
dloghyd	0.1137661	0.0393779	2.89	0.011	0.0298342	0.1976981
dlogthe	0.3132093	0.0532026	5.89	0.000	0.1998106	0.426608
_cons	0.0673104	0.0063463	10.61	0.000	0.0537836	0.0808373

Next, a robustness test is performed. The first is the replacement of renewable energy types, and Table 4 displays the outcomes of the replacement. The results indicate that at a 5% level of significance, the growth rates of wind power generation and electricity consumption per unit of GDP are statistically significant, while the relationship between nuclear power generation is not significant. This result can be explained that China's wind energy development has received a lot of investment and policy support in recent years, and both the production and supply sides have high expectations

for the wind energy industry. Yet, China uses relatively little nuclear energy. In 2021, only 5.02% of the country's electricity was produced using nuclear energy. The nuclear-powered generation industry was not connected to the national grid for power generation until 2021, which is outside the scope of the data set in this paper [12]. In addition, the coefficients in the results are the same as those in the basic regression, showing a positive correlation.

In addition, the variable electricity consumption per unit of GDP is replaced, and the results are shown in Table 5. The relationship between the growth rate of hydropower production and GDP is tested here, and the outcomes correspond to those obtained earlier. The growth of the GDP is positively correlated with hydropower, with hydropower having a smaller influence on GDP than thermal power. In addition, the contribution of both to the development of total electricity production is tested here at the same time. The result is that thermal power is expanding far faster than hydropower, which is in line with the explanation of the insignificant correlation between hydropower and unit GDP in the part of the descriptive statistics.

Table 4: robustness test on X

VARIABLES	(1) con	(2) con
dlognuc	0.006	
	(0.023)	
dlogthe	0.291***	-0.052
	(0.062)	(0.044)
dlogwin		0.062**
		(0.024)
Constant	0.078***	0.072***
	(0.006)	(0.005)
Observations	18	10
R-squared	0.570	0.591

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Table 5: robustness test on Y

VARIABLES	(1) rgdp	(2) dlogpro
dloghyd	13.674**	0.122***
	(5.304)	(0.012)
dlogthe	37.461***	0.746***
	(9.359)	(0.013)
Constant	4.645***	0.018***
	(1.218)	(0.002)
Observations	18	18
R-squared	0.656	0.992

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

At last, this research also grouped regions according to the distribution of hydropower generation in various provinces in China and conducted a heterogeneity analysis on the growth rate of hydropower generation and regional GDP. However, the data of the two groups of provinces did not show a significant relationship, which is considered to be since the grouping of provinces by energy or economic development cannot avoid the influence of regional development differences and differences in natural conditions, coupled with many variables that need to be controlled (trade, climate, education, policies, etc.).

6. Conclusion

6.1. Findings

Research indicates that there is a correlation in economy expansion and the electricity production with renewables. The relevance of the connection among different types of renewables and economy expansion also varies due to changes in market shares and energy sources. The energy system still relies heavily on thermal power. According to certain studies, industrialized and developing nations have different relationships with new energy development and economic development. China as the greatest developing nation in the world, is still in a phase when expanding the production of thermal power and even increasing investment in traditional fossil energy have a positive influence on the economy's expansion.

Moreover, economic expansion encourages the development of renewable energy sources together with modifications to investment strategies and policy impacts. This is in line with Hypothesis 3, which asserts that economy expansion and renewable energy development are intertwined. The Chinese government continues to increase its emphasis on the green energy industry and promote energy structure as well as supply-side reforms, which are of positive and great significance to the green transformation and sustainable the expansion of the Chinese economy. Although renewable energy's development does have influence on the traditional energy industry, the transition can still contribute to economy expansion in the short term. Over time, the environmental and climate pollution caused by traditional fossil energy will hinder economic development much more than the losses caused by transformation.

6.2. Research contributions and limitations

In summary, the primary contribution of this investigation is to illustrate the relation between the expansion of renewable energy power generation and economy development, which may aid nations in developing their development strategies when resolving the conflict between the economy and the environment. Moreover, the study also offers a theoretical base for the growth of renewable energy, where its development conflicts with traditional ones.

However, this research has certain limitations and recommendations for future directions that need to be mentioned. The study strictly focuses at panel data from China during the last 20 years. Due to the short period of new energy development, the sample size is limited. Coupled with the impact of the epidemic, some of the latest data cannot be obtained. Therefore, future research can conduct a more in-depth analysis of the problem with more data support and a wider selection of variables. In addition, the interaction between various energy sources can be further studied from the perspective of policy.

The model design of the heterogeneity analysis part can also be studied in greater depth. Future studies scrutinizing the connection in provincial renewables and GDP growth may incorporate other factors, or regions can be divided using more precise models, to make the findings more practical.

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