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The Effect of Clean Energy Power Generation on Economic Growth in China: A Perspective Based on Econometric Methods

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Abstract. To study the impacts of clean energy industry development on economic growth, we have established an econometric model based on the Cobb-Douglas production function. The methods mainly include the cointegration test, vector auto regression model (VAR), vector error correction model (VECM), Granger causality test and impulse response function. As for the obtained results, the paper analyzes the major impacts of clean energy power generation on economic growth from the perspective of four factors: the long-term equilibrium, the short-term fluctuation, the causality and the impulse responses. Moreover, a multiple-linear regression model has been effectively used to analyze the contributions of two kinds of clean energy (hydro energy and new energy) to GDP growth. The results demonstrate that the generation of clean energy may significantly promote long-term economic growth. Notably, this positive influence requires clean energy to have developed to a mature stage. It is suggested that certain novel energy policies could play a critical role in the improvement and upgrading of China’s energy industry.

Introduction

In past decades, fossil energy, such as coal, oil and natural gas, was the main energy source and the most important driver of economic growth and social development. However, with the depletion of fossil fuel resources and increasingly serious pollution problems, traditional fossil fuels can no longer meet the needs of modern society in terms of low-carbon development [1]. Today, the concept of sustainable development is advocated all over the world. Under this situation, clean energy has developed rapidly and its exploitation has undoubtedly become a major trend in future resource utilization [2].

Clean energy, also called green energy, is characterized as environmentally friendly, with low emissions and low pollution. It covers a wide range of energy types. For instance, hydro and nuclear energy have been exploited and utilized broadly for decades, and other newer types of renewable energy (including solar, wind, and biofuel, geothermal and tidal) have attracted extensive attention in recent years. Many countries have recently been actively developing clean energy for the following purposes: (i) to mitigate crises related to energy shortages and promote low-carbon development; (ii) to optimize energy structure and promote industrial transformation; (iii) to cultivate new drivers of economic development [3].

The World Energy Outlook 2017 (issued by the International Energy Agency) [4] noted that the share of renewable energy relative to total power generation globally is predicted to reach 40% by 2040. According to the BP Statistical Review of World Energy 2017 (issued by the BP group) [5], the world energy structure is transferring rapidly toward low-carbon energy, with renewable energy growing fastest. Based on the current energy situation, many countries have developed incentive policies to support clean energy development, such as the US Clean Power Plan, the US Photovoltaic Industry Road Map Through 2030 and Beyond, the German Renewable Energy Law, the Japanese Renewable Energy Subsidy Policy, etc [6]. Accordingly, worldwide consensus has developed on the importance of promoting clean energy development.

In China, clean energy development has entered a rapid growth period. According to the 2017 Renewable Energy Development Plan of China [7], by 2020, non-fossil energy will account for 15% of total national energy consumption, while the proportion represented by coal will reduce to less than 58%, thus further optimizing the national energy structure. Moreover, the total installed capacity of clean energy will exceed that of coal power generation by 2030. Many areas of China are rich in solar, wind, biofuel or marine energy resources, the effective utilization of which will become a strong positive force promoting regional economic growth.

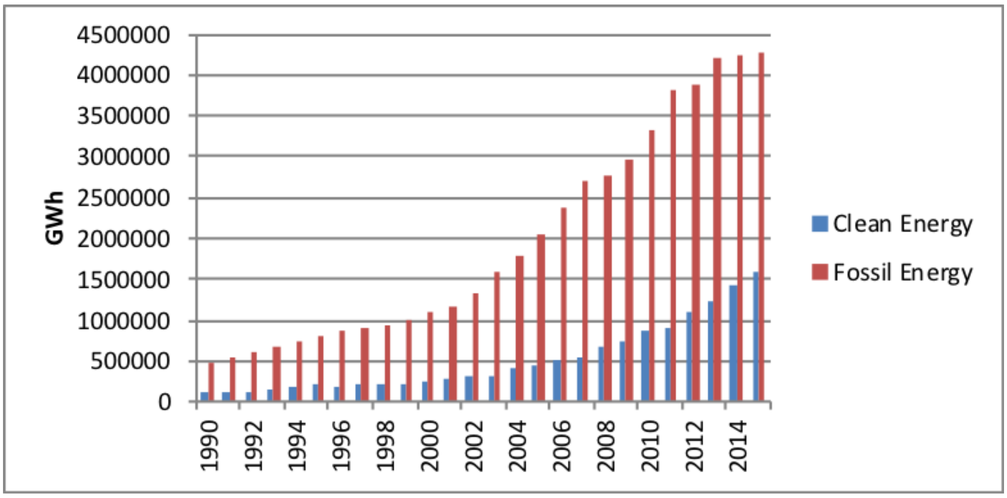

Fig. 1 China electricity production of clean energy and fossil energy: 1990-2015. Source: IEA.

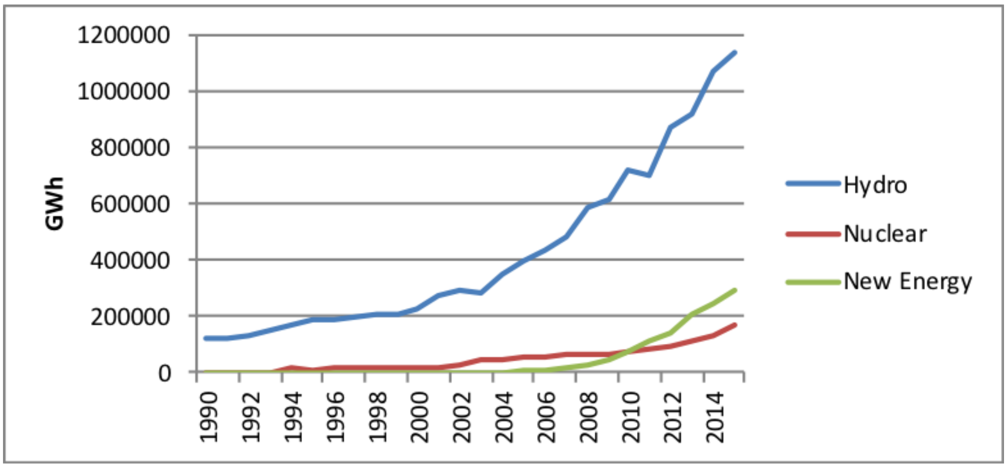

Fig. 2 China electricity production from three types of clean energy: 1990–2015. Source: IEA.

In this paper, we will report on analyses of the impacts of clean energy development on economic growth in China. Firstly, the interrelationship between clean energy and economic growth is studied using econometric methods. The theoretical model used for data analysis is based on the Cobb-Douglas production function and includes five variables: economic growth (measured by GDP), fossil energy, clean energy, capital stock and labor force. To effectively illustrate the correlations and interplay among these variables, the paper adopts several quantitative analysis methods, i.e. stationarity test, cointegration test, vector auto regression model (VAR), vector error correction model (VECM), Granger causality test and impulse response function analysis. Secondly, a multiple linear regression model is used to analyze the influence of hydro and new energy on GDP growth, and certain main impacts are discussed in detail. Finally, based on the obtained data, the paper puts forward several policies and makes proposals for further research on clean energy in China.

Literature Review

Before the 1970s, most classical economists focused on the contribution of conventional production factors, such as capital and labor. In contrast, energy was considered an inexhaustible natural resource and not seriously accounted for. Only when the "oil crisis" occurred in the 1970s did energy problems begin to attract the attention of economists. In 1972, Meadows [8] constructed models that used renewable energy, traditional fossil energy and population growth rate to make socioeconomic predictions for the period from 1970 to 2100. In 1974, Heal [9] incorporated the nonrenewable energy factor into the Ramsay model, and found an alternative relationship between resource consumption and man-made capital. Since then, increasingly studies have explored the relationship between energy consumption and economic growth.

In 1992, Yu [10], using data from 1974 to 1990, found no significant long-term equilibrium relationship between energy consumption and economic growth in the United States. In 1997, Glasure [11] studied the relationship between energy consumption and economic growth in Korea. Through the Granger causality test and error correction model, it was found that the results obtained using different methods were not unique. In 2003, Yetkiner [12] expanded the Romer model and set energy consumption as an intermediate variable. A negative correlation was found between economic growth rate and the rate of increase in energy prices. In 2007, Mehrzad [13] conducted an econometric analysis of selected oil exporting countries and found one-way Granger causality between economic growth and energy consumption.

In recent years, with the rapid development of the clean energy industry, as well as progress in economic research methods, such as quantitative methods, statistics and computer technology, has stimulated rapid progress in the study of the relationship between clean energy and economic growth.

Model and Data

The production function represents the economic relationship between the combination of all input elements and the maximum output in the production process. Its general form is $Y=f(X_1, X_2 \ldots\ldots X_k)$, where Y represents output (production), and $X_1, X_2 \ldots X_k$ represents input elements.

There are many common forms of production function, such as fixed substitution proportion production function and fixed input proportion production function. This paper introduced energy elements into production function based on the Cobb-Douglas function form [14], and obtained the following equation (Eq.1) after transformation:

$$Y_t=F\ (L_t,\ K_t,\ E_t,\ CE_t)\ =AL_t^{\alpha}K_t^{\beta}E_t^{\gamma}CE_t^{\delta} \tag{1}$$

Where Y_t represents real GDP, L_t represents size of the labor force, K_t represents fixed capital stocks, E_t represents fossil energy inputs, CE_t represents clean energy inputs, and A, which is treated as a constant, represents technological progress and other factors that affect economic growth.

To eliminate heteroscedasticity, the paper takes the logarithm of the equation and gets the model form (Eq. 2) as follows:

$$\ln Y_t=\ln GDP_t=\ln A+\alpha \ln L_t+\beta \ln K_t+\gamma \ln E_t+\delta \ln CE_t+\mu_t \tag{2}$$

In the following econometric analysis, various regression tests of the sequences are conducted against five variables: lnY (lnGDP), lnL, lnK, lnE and lnCE. The paper chooses Chinese data from 1990 to 2015, as follows:

(i) Real GDP. Using the nominal GDP and the GDP index (1978 =100) published in the China Statistical Yearbook [15], it is possible to calculate the real GDP (Unit: hundred million Yuan). The formula is: real GDP in year t = real GDP in 1978 ×(GDP index ÷100).

(ii) Fossil energy and clean energy inputs. Generally, econometric models dealing with energy elements choose energy consumption as an input. Because the consumption data released by the International Energy Agency (IEA) is limited, this paper adopts gross electricity generation (Unit: GWh) as an alternative. All data are taken from the IEA Report, in which electricity generation is listed by source, with fossil energy sources including coal, oil and gas, and clean energy sources including hydro, nuclear, wind, solar, biofuel, waste, geothermal, tidal and wave [16].

(iii) Fixed capital stock. Currently, no authoritative data exists on China's social capital stock. Most studies estimate capital stock using the perpetual inventory method. This paper directly adopts the capital stock data estimated by Wang Wei [17].

(iv) Size of labor force. In this paper, the data of labor force is taken directly from the China Statistical Yearbook.

Econometric Methodology

Unit Root Test

To avoid pseudo regression problems and ensure effective results, firstly, a stationarity test (unit root test) is performed for all variables. Commonly used test methods include the DF test, ADF test, PP test, KPSS test and so on [18]. This paper chooses the ADF method. If the original sequence is nonstationary then testing of the variables' differential sequence continues until all sequences are stationary.

Table 1 ADF unit root test.

Variables	Level			1st difference			2nd difference		
	T- statistics	Intercept	Trend	T- statistics	Intercept	Trend	T- statistics	Intercept	Trend
lnGDP	-3.300391*	Y	Y	-0.606956	N	N	-5.535025**	N	N
lnE	-1.493405	Y	Y	-1.500834	N	N	-2.076335**	N	N
lnCE	-1.676827	Y	Y	0.378930	N	N	-5.637979**	N	N
lnK	-2.888414	Y	Y	-0.260841	N	N	-4.573023**	N	N
lnL	-0.792381	Y	Y	-1.661573*	N	N	-5.033847**	N	N

* and ** represent significance at 10% and 5% level respectively. Different combinations of intercept and trend are included in the test, where "Y" indicates "YES" and "N" indicates "NO". The form and optimal lags are selected based on the values of Akaike Info Criterion and Schwarz Info Criterion.

According to the results in Table 1, all variables are second-order difference stationary (at the 0.05 significance level), which means the variables constitute a second-order integration I(2), and therefore the cointegration test can be subsequently conducted.

Cointegration Test

The cointegration test is used to determine the long-term equilibrium relationship among variables. Several methods are frequently used, including the Engle-Granger method and Johansen maximum likelihood method [19]. The former mainly aims at the two-variable model, which requires that the system have a unique cointegration relationship. In this paper, the Johansen cointegration test is adopted to establish the multivariable model.

Firstly, the optimal lag order of the VAR model is determined under the situation of adequate lag length and degree-of-freedom, and the resultant data is 2. A VAR (2) model is then established for conducting the Johansen cointegration test.

Table 2 Johansen cointegration test.

Hypothesized No. of cointegrations	Trace test		Max-Eigen test	
	Trace Statistic	Critical Value (5%)	Max-Eigen Statistic	Critical Value (5%)
R=0 (None)	121.8164*	69.81889	48.40499*	33.87687
R≤1 (At most 1)	73.41144*	47.85613	35.21271*	27.58434
R≤2 (At most 2)	38.19873*	29.79707	25.31836*	21.13162
R≤3 (At most 3)	12.88037	15.49471	8.858480	14.26460

* represents rejection of the hypothesis at the 5% level.
Trace test and Max-eigenvalue test both indicate 3 cointegrating equations at the 5% level.
Assumption of the cointegration test allows for linear deterministic trend in data, and intercept (no trend) in CE.

Table 2 shows the obtained results and clearly illustrates the Trace and Maximum Eigen values. Notably, a visible cointegration relationship exists among the variables. Particularly, the long-term equilibrium relationship can be addressed among GDP, fossil energy, clean energy, capital stock and labor force.

The cointegration equation can be written as:

$$\ln GDP=0.293402\ln E+0.0985851\ln CE+0.203174\ln K+2.828169\ln L-28.77326 \quad (3)$$

In the long term, fossil energy, clean energy, capital stock and labor force corelate positively with economic growth, and a 1% increase of lnE can drive a 0.29% rise in lnGDP, while a 1% increase of lnCE can drive a 0.099% rise in lnGDP. Furthermore, the contribution of fossil energy is about three times that of clean energy, which reflects the reality that fossil currently, remains the predominant source of energy in China.

Vector Error Correction Model

The vector error correction model (VECM) can be constructed according to the cointegration relationship among the variables. The VECM model can be used to analyze the relationship between short-term fluctuation and long-term equilibrium, revealing the nature of variable adjustments to the equilibrium state after a short-term deviation [20]. The coefficient of the differential form of every explanatory variable reflects the influence of fluctuations on short-term changes of the relevant variable.

Table 3 The VECM analysis.

Error Correction	CointEq1	D(LNGDP(-1))	D(LNE(-1))	D(LNCE(-1))	D(LNK(-1))	D(LNL(-1))	C
D(LNGDP)	-0.299326** [-7.27534]	0.347985** [2.62893]	-0.089214 [-1.38815]	-0.039369 [-1.21766]	0.004436 [0.07334]	-4.626073** [-4.82592]	0.107211** [5.66631]

** represents significance at 5% level.

In Table 3 the error correction coefficient of D (LNGDP) is -0.299479, and the negative value suggests an inverse correction mechanism in the present case. The variable lnGDP can be dynamically adjusted to an equilibrium state for the deviated data. Notably, from the results of the ECM equation of D(LNGDP), the T-statistics of D(LNGDP(-1)) and D(LNL(-1)) are significant at the 5% significance level, demonstrating that the reverse adjustment effects of economic growth mainly arise from fluctuations in the rate of economic growth itself and in the labor force.

Granger Causality Test

The paper now explores the statistical causal relationship between the variables using the Granger causality test [21]. Because the alteration of lag length is known to be sensitive to analysis of the results, different lag periods are selected in this study. Table 4 shows the Granger causality results, illustrating the correlation among lnGDP, lnE and lnCE. It is shown that for the lag period of 2, lnE has one-way causality to lnGDP, and lnGDP has one-way causality to lnCE. This suggests that under certain conditions fossil energy electricity generation statistically leads to economic growth. On the other hand, economic growth clearly promotes clean energy electricity generation.

Table 4 Granger causality analysis.

Null hypothesis	Lag length	F-statistics	Probability
LNGDP does not Granger Cause LNCE	1	3.32042*	0.0820*
LNCE does not Granger Cause LNGDP	1	0.01546	0.9022
LNGDP does not Granger Cause LNE	1	0.15638	0.6963
LNE does not Granger Cause LNGDP	1	17.1008**	0.0004**
LNGDP does not Granger Cause LNCE	2	3.09270	0.0687
LNCE does not Granger Cause LNGDP	2	0.13128	0.8778
LNGDP does not Granger Cause LNE	2	0.29365	0.7489
LNE does not Granger Cause LNGDP	2	5.25688**	0.0152**
LNGDP does not Granger Cause LNCE	3	1.93299	0.1650
LNCE does not Granger Cause LNGDP	3	1.21386	0.3368
LNGDP does not Granger Cause LNE	3	0.57054	0.6425
LNE does not Granger Cause LNGDP	3	0.44648	0.7231

* and ** represent rejection of the hypothesis at the significance at 10% and 5% level respectively.

Impulse Response Function Analysis

In this study, the generalized impulse method, which does not depend on the order of variables, is used to analyze the dynamic impact on economic growth from the application of an impulse to either fossil energy or clean energy. Conversely, analysis of the impact of energy is also performed for an impulse applied to economic growth [22].

As illustrated in Fig. 3, the effects on both lnE and lnCE are continuously fluctuating around zero when lnGDP gets an impulse, which indicates that sudden change in economic growth has limited influence on energy usage. On the other hand, when lnE gets an impulse, lnGDP exhibits positive effects after the fourth period, after which it continuously grows to reach a stable state. When lnCE gets an impulse, there is a significant negative effect on lnGDP, which tends to be stable after the tenth period. These results clearly demonstrate that fossil energy usage can promote economic growth, and utilization of clean energy negatively affects economic growth.

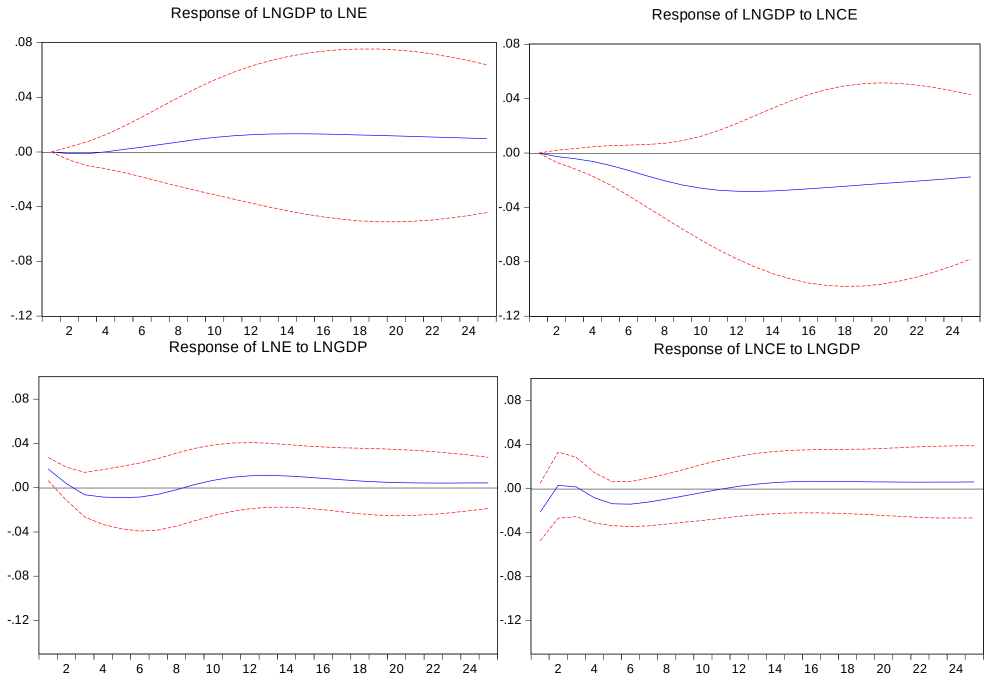

Fig. 3 results obtained from impulse response analysis

Contribution Rate Analysis

Hydro is the most mature form of clean energy in China. In comparison, new energy, which is mainly represented by solar and wind, remains at an early stage of development. According to the results mentioned in the previous section, the mutual influence correlation between clean energy and economic growth (GDP) could be further studied for clean energies in China. To study the contribution rates of two typical kinds of clean energy, i.e. hydro energy and new energy, a multiple linear regression model is built. The results can be characterized using the following equation:

$$Y=0.013636X_1-0.025875X_2-675.6337 \quad (4)$$

$$(12.314) \quad (-6.353) \quad (-2.069)$$

$$R^2=0.935 \quad \text{Adjusted } R^2=0.93 \quad \text{F-stat}=166.5 \quad \text{D.W.}= 2.178$$

Where Y is GDP growth (ΔGDP), X_1 is hydro energy, and X_2 is new energy, which includes wind, solar, biofuel, waste, geothermal, tidal and wave.

Based on the values of R^2 and Adjusted R^2, the goodness-of-fit (GOF) of this linear regression equation is very high. Also, the T-statistics (i.e. (12.314), (-6.353), (-2.069)) of all coefficients are significant. From the D.W. value, no sequence correlation exists in the present equation. On the other hand, the White Test (see Table 5) shows no heteroscedasticity. Therefore, this equation shows good explanatory and reference significance.

Table 5 White Heteroskedasticity Test

Null hypothesis	F-statistic	Prob. F(5,20)
The collection of variables is heteroscedastic	1.699928	0.1807

As for the typical results obtained from present analysis, an increase in X_1 of 1% will drive an increase in ΔGDP of 0.014%. In contrast, an increase in X_2 of 1% will decrease ΔGDP by 0.026%. It can be seen that the usage of new energy (represented by X_2) in China has negative impact on GDP growth since it is at initial stage of development [23].

Conclusion and Policy Implications

In summary, our extensive study based on the Cobb-Douglas production function and related data analysis reveals notable influences of clean energy and fossil energy on economic growth. Comparing the effects on GDP growth in China of two kinds of clean energy, namely water energy and new energy, the following conclusions are drawn:

1. According to the cointegration test results, a long-term equilibrium relationship exists between economic growth, clean energy, fossil energy, capital stock and labor quantity. Moreover, the latter four variables are positively correlated with economic growth. That is, in the long term, all four variables positively affect economic growth. Simultaneously, the contribution of fossil energy to economic growth is about three times that of clean energy.

2. According to the causality test results, a one-way causality exists from fossil energy to economic growth, and also from economic growth to clean energy. Fossil energy, as the main form of energy used in China, is important in promoting economic growth. Although a new form of energy, clean energy has developed rapidly in recent years, and now accounts for a small but significant proportion of total energy consumption. It is expected that economic growth can promote the development and use of clean energy.

3. According to the results of impulse response analysis, the application of an impulse to economic growth has limited influence on fossil energy or clean energy; when fossil energy receives an impulse, economic growth will exhibit a visible positive effect; when clean energy receives an impulse, the effect on economic growth will be visibly negative. These facts show that, at least in terms of short-term fluctuations, clean energy may somewhat impede economic growth.

4. The results obtained from multiple linear regression models clearly reveal that the usage of

water energy will increase GDP growth, while that of new energy will decrease it. This is because during the initial stage of development new energy has high technology costs and low utilization efficiency, and therefore its rapid development will negatively impact economic growth.

Based on the relevant conclusions obtained in the present study, the paper proposes the following policy recommendations:

1. Maintain the stability and sustainability of energy policy. According to this study, China's energy consumption continues to be dominated by fossil energy and is essentially inseparable from social development. Moreover, clean energy, especially new energy, remains in the initial stage of development, with high technological cost and low energy utilization rate. Therefore, when promoting the transformation and upgrading of energy, instead of excessive restrictions on fossil fuel use, the government should gradually implement policy consistent with the actual conditions of various industries. Moreover, the promotion of clean energy should consider long-term stability policy, otherwise it may impede sustainable social development [24].

2. Encourage the development of clean energy diversification. In the long run, both fossil energy and clean energy are important resources for industrial development, and both play critical roles in promoting economic growth. Simultaneously, for fossil energy, the characteristics of high pollution, low efficiency and the reality of exhaustion make the development of clean energy both urgent and necessary. Therefore, the government should develop and utilize clean energy, especially new energy resources such as solar, wind and biofuels, to constantly expand energy sources varieties, broaden energy supply channels, and eventually diversify energy development to provide sufficient dynamics for long-term stable economic growth.

3. Adopt subsidies and preferential policies and encourage technological innovation. Clean energy is not yet a mature industry, and lags fossil energy in terms of both market share and public awareness. Additionally, clean energy resources are widely distributed and dispersive, meaning greater risks and costs associated with exploitation and utilization. Therefore, the development of clean energy must rely on government financial support, such as tax preferential policies to effectively reduce enterprise R&D and operating costs. Since technical advance is an important way to improve utilization efficiency and reduce exploitation costs, the government should focus on encouraging innovation in core technology to ensure the continuous development of the clean energy industry.

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