Environment, Resource and Ecology Journal (2022)
Clausius Scientific Press, Canada

DOI: 10.23977/erej.2022.060404
ISSN 2616-3756 Vol. 6 Num. 4

The Impact of Energy Substitution on the Output Efficiency of the Industrial Economy

Liang Zhang

School of Management, Shanghai University, China

Keywords: Energy substitution, CD production functions, Output efficiency

Abstract: As China's industrial economy enters a phase of rapid growth rate shifting, structural adjustment, and new energy development, recent changes in growth momentum are required to support the shift from high-speed growth to high-quality development. Based on the input-output model, CD production functions are employed to assess the feasibility of a transition from raw coal, crude oil, to clean energy sources (wind power, hydropower, photovoltaic generation, and nuclear power). The study also assesses the feasibility of an energy transition in five provinces under the Southern Power Grid between 2000 and 2018. According to the study, fossil energy remains the primary driving force for industrial development in the current energy technology environment. Clean energy cannot fully replace fossil energy in the short term. Moreover, the output benefits of clean energy are different in different regions based on the level of per capita income.

1. Introduction

Even though China's economy has boomed since the reform and opening up, environmental degradation and energy depletion have become increasingly serious problems, and green and sustainable development have drawn the attention of all sectors. According to the World Energy Statistics Yearbook, China consumed 23.77% of the world's fossil fuels in 2018, while clean energy consumed 28.87% and total carbon emissions accounted for 27.82% of the world. According to the 2018 National Bureau of Statistics data, raw coal made up 68.6% of China's energy production structure in 2017, crude oil made up 7.6%, and hydropower, nuclear power, and wind power accounted for 18.3%. The energy consumption structure contains a significant amount of coal, which accounted for 60.4% of total energy consumption, a decrease of 1.6% year on year. Among the world's largest energy producers and consumers, China produces and consumes a significant amount of energy. In a country with a resource endowment of "rich coal, poor oil, and little gas", coal continues to dominate. Oil consumption is high, but production is low. Therefore, imports are necessary. Clean energy consumption is on the rise, and the development potential is considerable. Moreover, China has become the world's largest carbon emitter since 2005, and the pressure from the global community to address climate change has increased. Despite the epidemic of 2020, Nearly 10.5 billion tons of carbon dioxide are emitted by China each year, with over 85% of carbon emissions resulting from energy production. In spite of the fact that the total industrial economy is growing rapidly, it is becoming increasingly important to address issues such as energy depletion and environmental degradation. In addition, green and sustainable development has become an issue of major concern across all sectors of the society.

Aside from demonstrating an increased awareness of "energy savings and consumption reduction", the Chinese people also show a strong desire for "clean and environmental protection". In light of the continuing decline in fossil energy consumption and the increase in the use of clean energy, the question remains whether clean energy can replace fossil fuels or whether there will be a complementary effect between fossil fuels and clean energy, as well as how fossil fuels and clean energy will affect the industrial economy. It is important to examine in depth whether "replacing coal with electricity and replacing oil with electricity" is feasible and to what extent it can be replaced. Specifically, this paper examines the five provinces of the Southern Power Grid (Guangdong, Guangxi, Hainan, Yunnan, and Guizhou). All these provinces have different levels of clean energy production capacity, per capita income, and industrial development. Using these methods, it is possible to examine the utilization rate of clean energy and output efficiency at various per capita income levels that are highly representative of the population.

2. Literature review

The transition to sustainable energy is a long-term, multidimensional and foundational endeavor [1] Furthermore, it is a way of transforming socio-technical systems into more benign modes of production and consumption [2]. In addition to the transformation of energy infrastructure, the energy transition involves the conversion of a "broader socio-economic mix" as well [3-4]. There will be a global impact on China's energy transition [5] and there must also be new ideas in the 'new era' energy security strategy [6]. China should fundamentally break the cycle of "expansion-excess-re-expansion-excess" in the industrial sector [7]. In the "transition period, energy structure adjustment, accelerating green and low-carbon development, improving energy system efficiency, and pursuing comprehensive operational benefits will become the primary goal" [8]. Climate change and environmental protection are also addressed in alternative-complementary relationships in the energy transition. Due to rapid technological advancements and economic progress in China, as well as the current improvement in people's living standards, the desire for a high-quality life is growing stronger and stronger. International diplomacy, military, politics, and the economy have become increasingly concerned with issues such as the environment, energy substitution, energy efficiency, and economic growth, particularly how to promote the coordinated development of the economy, energy, and environment. This is not only essential for sustainable economic development but also one of the main challenges to be solved by current human development. Research on energy and energy substitution, capital, and environmental pollution is one of the most important topics in the fields of energy economics and environmental science. At the present time, the National Power Dispatching and Control Center has organized the China Electric Power Research Institute to develop a cross-regional inter-provincial surplus clean energy spot trading technical support system. By promoting market competition and using water, wind, and photovoltaic energy to their fullest extent, we will be able to fully excavate the interprovincial consumption space for clean energy. In addition to various medium-and long-term delivery plans and transactions, the market is positioned as an incremental delivery transaction for surplus clean energy power generation. The resources regulated on the side of the provincial power generation system and the side of the negative load system at the sending end have been exhausted. Clean energy still has surplus power generation capacity, and water and wind may be abandoned as a result. Using the surplus transmission capacity of the State Grid Power Dispatching and Control Center within the existing policy framework, it is necessary to directly adjust the interregional channel, organize and execute interprovincial and intra-provincial transmission transactions in a market-oriented manner, and consume as much clean energy as possible within the existing policy framework.

The impact of industrial energy transition on economic output in various provinces and cities is not adequately examined in the existing studies. Several studies have been conducted on the relationship between energy technology progress and economic growth [9], the connotation of energy transition [10], the path of the energy transition [11], energy transmission, and the energy transition model [12]. Regarding existing research, the marginal contributions of this paper are (1) Analyzing the efficiency of clean energy output in the Southern Power Grid region using the Cobb-Douglas (CD) production function; (2) The horizontal comparison of these five provinces and regions; (3) The conclusion that clean energy output efficiency differs depending on the economic and technological level at which it is produced.

3. Methods and data

According to Yang [13] et al., this paper employs the Cobb Douglas production function to estimate the output effect of energy, which is generally defined as follows:

$$Y_i = A_i K_i^{\alpha} d_{i1}^{\beta} d_{i2}^{\eta} r_i^{\upsilon} \quad (1)$$

The region is represented by *i*, the output *is* represented by *Y*, the rate of technological advance is represented by *A*, the amount of capital input in the region is represented by *K*, raw coal and crude oil are represented by d_{i1} and d_{i2}, respectively, and clean energy is represented by *r*. There are two different input factors for the production of energy: fossil fuels and clean energy. Most of the existing research, however, does not differentiate between the contributions of fossil energy and clean energy to output in terms of capital, labor, and energy. Accordingly, raw coal, crude oil, and clean energy are considered independent production factors in this study.

(1) Output (*Y*). As a measure of output, this study uses the constant-price industrial value added of each province based in 2000.

(2) Capital investment (*K*). For this paper, capital stock is used as a capital variable, and the perpetual inventory method is employed to estimate the capital stock of each province. The formula is expressed as follows:

$$K_{t+1} = I_{t+1} + (1-\delta)K_t \quad (2)$$

Where the year is represented by *t*, capital depreciation rate is represented by δ, the amount of capital investments in the current year is represented *by I*, and the accumulated capital stock is represented by *K*.

(3) Fossil energy inputs (*d*). In this paper, fossil energy consumption is used as the input variable for fossil energy, and industrial raw coal and crude oil consumption is used as the inputs for fossil energy.

(4) Clean Energy Input (*r*). Considering the availability of data, the paper uses clean energy power generation as a proxy for clean energy input, and expresses it as the sum of hydroelectric power generation, wind power generation, nuclear power generation, and solar power generation.

4. Methods and data

4.1. Descriptive statistics and correlation analysis

Data from 5 provinces of China Southern Power Grid (Guangdong, Guangxi, Hainan, Yunnan, and Guizhou) were selected as a research sample based on the availability of data. To eliminate the effects of factors such as inflation, the capital stock and industrial value added are deflated in the price index to constant prices in 2000. China Statistical Yearbook is used to calculate industrial added value and its price index; China Fixed Asset Investment Statistical Yearbook is used to calculate capital stock data; China Labor Statistics Yearbook is used to calculate labor inputs; China Energy Statistical Yearbook is used to calculate fossil energy inputs, and China Electric Power Statistical Yearbook is used to calculate clean energy inputs. The missing data is supplemented by local statistical yearbooks for some years.

As shown in Figure 1, the descriptive statistics for the variables are as follows:

variable	N	mean	sd	min	max
output	95.0000	7.6480	1.4850	4.1860	10.2856
capital_	70.0000	16.7911	1.7049	12.6922	19.9685
d1	94.0000	8.3800	1.1587	5.1948	9.7347
d2	94.0000	3.6330	4.0346	-3.9120	8.6841
r	94.0000	5.6374	1.4709	2.2300	7.9899

Figure 1: Descriptive statistics.

According to Figure 1, the minimum and maximum values of economic output are 4.186 and 10.2856, respectively, and their variance is less than the mean, which indicates that there is no excessive dispersion in economic output. There is a significant negative correlation relationship between crude oil, raw coal, and clean energy based on the correlation coefficient matrix test at a significance level of 1%, and the correlation coefficient is less than 0.2. This indicates that crude oil, raw coal, and clean energy have no significant correlation, and there is no significant multi-collinear relationship.

4.2. Results of total sample regression

25 variable observations were deleted due to the absence of the yearbook of part of China's industrial economy. According to the regression analysis, 70 observations are presented in Table 2. Figure 2 illustrates specific regression results based on the following regression model:

$$Y = e^{-2.52887} K^{0.2697366} d_1^{0.5236822} d_2^{0.098316} r^{0.1920502} \tag{3}$$

Source	SS	df	MS			
Model	115.420303	4	28.8550757	Number of obs	=	70
Residual	7.04463864	65	.108379056	F(4, 65)	=	266.24
				Prob > F	=	0.0000
				R-squared	=	0.9425
				Adj R-squared	=	0.9389
Total	122.464942	69	1.77485422	Root MSE	=	.32921

output	Coef.	Std. Err.	t	P>|t|	[95% Conf.	Interval]
capital_	.2697366	.0493615	5.46	0.000	.1711549	.3683183
d1	.5236822	.0823037	6.36	0.000	.3593103	.6880541
d2	.098316	.0124165	7.92	0.000	.0735186	.1231134
r	.1920502	.0741802	2.59	0.012	.0439022	.3401983
_cons	-2.52887	.6377265	-3.97	0.000	-3.802498	-1.255242

Figure 2: Results of the total sample regression.

Based on Figure 2, It can be seen that the goodness-of-fit R square is 0.9425, which indicates a better fitting effect. At a significance level of 5%, the raw coal, crude oil, and clean energy variables all passed the significance test. In comparison to clean energy, raw coal has an output elasticity coefficient of 0.1920502, while clean energy has an output elasticity coefficient of 0.5236822. It is evident that the economic output elasticity of crude oil is the lowest in the industrial field, and raw coal still has an advantage in terms of cost and economic benefits. As a result, a comprehensive replacement for fossil fuels in the short term is impractical, even from an economic standpoint. Therefore, fossil fuel is the most important driving force for economic growth in the five provinces when there is no major change in industrial technology. Nevertheless, the promotion of clean energy for the development of the industrial economy of the five provinces cannot be overlooked.

4.3. Total sample regression results

The variance inflation factor is tested for all explanatory variables in this article, and the results are shown in Figure 3:

Variable	VIF	1/VIF
r	8.05	0.124155
d1	5.45	0.183451
capital_	4.51	0.221780
d2	1.75	0.569929
Mean VIF	4.94	

Figure 3: Variance inflation factor test.

Table 3 illustrates that the VIF value without explanatory variables is significantly greater than 10, indicating there is no serious multicollinearity, and an explanatory variable does not need to be deleted.

5. Sample test

As indicated above, clean energy plays a significant role in promoting the industrial economy of China Southern Power Grid's five provinces. Nevertheless, there are clear differences between the regions in terms of economic and technical development. A further analysis is conducted to determine the rate of technological progress in each province and the efficiency of energy production at different levels of technology. Based on a sample of five provinces, we developed a regression model as follows:

$$Y_1 = e^{2.7875} K^{0.2574} d_1^{-0.1056} d_2^{0.2467} r^{0.1810} \quad (4)$$

$$Y_2 = e^{-5.0370} K^{-0.1129} d_1^{1.2189} d_2^{0.2118} r^{0.5924} \quad (5)$$

$$Y_3 = e^{-1.6443} K^{0.3554} d_1^{0.2966} d_2^{0.1291} r^{-0.0995} \quad (6)$$

$$Y_4 = e^{-1.5766} K^{0.4362} d_1^{0.0207} d_2^{0.0000} r^{0.2916} \quad (7)$$

$$Y_5 = e^{1.2367} K^{0.3141} d_1^{0.0619} d_2^{-0.0043} r^{0.1336} \quad (8)$$

As shown in Table 1, the specific results are as follows:

Table 1: Regression results of the five provinces.

	Guangdong	Guangxi	Hainan	Guizhou	Yunnan
*Capital_*	0.2574*** (7.03)	-0.1129 (-0.59)	0.3554** (3.19)	0.4362*** (3.52)	0.3141 (1.38)
d1	-0.1056 (-0.84)	1.2189** (2.66)	0.2966 (1.74)	0.0207* (0.24)	0.0619 (0.21)
d2	0.2467* (2.01)	0.2118 (1.39)	0.1291** (2.96)	0.0000	-0.0043 (-0.31)
r	0.1810* (1.98)	0.5924* (1.87)	-0.0995 (-1.30)	0.2916* (1.61)	0.1336 (0.44)
_cons	2.7875*** (3.60)	-5.0370 (-1.59)	-1.6443 (-1.50)	-1.5766 (-0.50)	1.2367 (1.14)
N	14.0000	14.0000	14.0000	14.0000	14.0000
R^2	0.9964	0.9689	0.9528	0.9747	0.9648

Note: ***, **, and * indicate significant confidence levels of 1%, 5%, and 10%, respectively.

According to the regression results in table 1, clean energy can partially replace fossil fuels, but it cannot fully replace them in a short period. Industrial growth continues to be driven primarily by coal in Guangxi and Hainan. Hydropower is a major source of energy in Yunnan and Guizhou, and the benefits of using clean energy are greater than those associated with fossil fuels. The rapid development of green energy technology in Guangdong has resulted in greater economic benefits from clean energy. As a result, to improve the effectiveness of clean energy technologies in protecting the environment, we need to increase their flexibility as alternatives to fossil fuels. Therefore, we need to promote clean energy technologies throughout the value chain. Because of the market mechanism in innovation of clean energy technologies, the government should take a leading role in promoting clean energy technologies by using research and development subsidies, regulatory standards, and other policies to promote clean energy technologies across all industries, particularly upstream industries and energy-intensive industries. Second, we need to apply strict environmental regulations to industries that pollute, impose higher taxes on fossil fuels, and increase penalties for polluting the environment, to make clean energy technologies more competitive through the price mechanism.

6. Conclusions

This paper provides empirical evidence that fossil fuels and clean energy play a significant role in China's industrial economy and that clean energy plays a role in replacing fossil fuels to a certain extent. In addition, it indicates that fossil fuels cannot completely replace it in a short period. As an industrial cluster, the energy sector is both capital-intensive and technologically-intensive. Chinese efforts to promote "energy transition" at this stage suggest that the transition will encourage the transfer of capital and technology from highly polluting to clean energy, thus improving the quality of the energy economy.

It should be noted that China's "energy transition" is not a "zero-sum game" of energy technology. On the one hand, fossil fuels continue to play an irreplaceable role in industrial development, as well as provide certain opportunities for innovation and development. On the other hand, the cost and technology of clean energy power generation have become increasingly important factors in determining China's success or failure in its energy transition. It is important to realize that the energy transition is more than just "increasing the share of clean energy", nor is it simply about making clean energy more cost-competitive. Energy costs in China have been reduced by economies of scale and technology has been advanced comparatively, which results in a wide range of energy transition pathways. As long as there are no competitive pressures or restrictions on the industry's own development, the transformation and upgrading of clean energy power generation in the industry itself is superior to the transformation and upgrading of fossil fuel power generation. The energy industry has benefited from its enhanced development efficiency and transformation effect. Fossil energy cannot be replaced in the short term due to its basic and pillar status. The "energy transition" will be an orderly and long-term process and is irreversible in the long run. A smooth, orderly, and efficient "energy transition" requires coordination between energy substitution and energy production.

First, the purpose of this paper should be to actively change the substitution relationship between fossil fuels and clean energy in order to speed up the replacement of fossil fuels with clean energy. Therefore, in order to promote the development of clean energy industries, provinces should create a high-quality development environment. As Guizhou and Yunnan's clean energy power generation accounts for close to 20% of the national power generation, it is imperative that these provinces provide more preferential policies for clean energy power generation related enterprises, especially for hydropower-related enterprises in their infancy. Certain subsidies will be provided and supported to improve market competitiveness, expand the share of clean energy in the energy market, accelerate the construction of infrastructure to use clean energy, and promote the use of clean energy in production technologies to achieve an effective alternative to fossil fuels. As a result of the national energy and power layout, the following measures should be taken: accelerate the transition to clean energy and develop a large-scale integrated energy base for fossil fuels and clean energy in the northern part of the west; encourage the construction of large hydropower facilities in southwest areas; encourage the development of distributed photovoltaic and decentralized wind power plants in eastern and central regions, and develop nuclear power and offshore wind power in coastal areas. In order to achieve complementary wind and solar storage, flexible transfer, and large-scale safe consumption, we need to construct a UHV large power grid that will serve the main functions and purposes of wind power and photovoltaic new energy generation, collection, transmission, and consumption. With integrating storage and distribution technologies, networking, flexibility, interaction, etc., we can release and use the power grid's resources in a scientific and orderly manner, mobilize user resources for coordinated interaction, promote market-oriented electricity trading, and achieve a win-win construction goal for all shareholders (by offering free capacity, slightly increased capacity, and reasonable capacity increases in power grid companies). The technical bottleneck needs to be overcome by looking for breakthroughs in industrial and agricultural production, civil engineering, and transportation, and using "efficient electric heat conversion technology, heat storage technology, intelligent regulation technology, and efficient electric technology" to increase the electrification rate in primary energy consumption significantly.

References

[1] Sovacool B K. How long will it take? Conceptualizing the temporal dynamics of energy transitions[J]. Energy Research& Social Science, (2016) 13, 202-215.

[2] Ponta L., Raberto M., Teglio A. An agent-based stock-flow consistent model of the sustainable transition in the energy sector[J]. Ecological Economics, (2018) 145, 274-300.

[3] Miller C A., Iles A, Jones C F. The social dimensions of energy transitions: Introduction to the special issue[J]. Science and Culture, (2013) 22, 135-148.

[4] Oudes D., Stremke S. Spatial transition analysis: Spatially explicit and evidence based targets for sustainable energy transition at the local and regional scale[J]. Landscape&Urban Planning, (2018) 169, 1-11.

[5] Shi, D. Policy measures to accelerate the energy transition [J]. Economic Research Reference, (2016) 71, 31-32.

[6] Shi, D. Energy transition and low-carbon industrialization path [J]. Theoretical Horizons, (2017) 11, 29-32.

[7] Jin B. The transformation and upgrading of China's industry [J]. China Industrial Economics, (2011) 7, 5-14.

[8] Zhou D D. Energy will not be transformed as soon as possible and will be abandoned by the world trend [J]. China Petroleum Corporation, (2016) 8, 24-25.
[9] He X G., Wang Z L. Energy bias towards technology-based technological progress and green growth transition [J]. China Industrial Economics, (2015) 2, 50-63.
[10] Elshurafa A., Farag H., Hobbsd A. Blind spots in energy transition policy: case studies from Germany and USA [J]. Energy Reports, (2019) 5, 20-28.
[11] Elshurafa A., Farag H., Hobbsd A. Adverse effects of rising interest rates on sustainable energy trainsitions [J]. Nature sustainability, (2019) 2, 879-885.
[12] Elshurafa A., Farag H., Hobbsd A. Tzakova Z. Public policy spillovers from private energy governance: new opportunities for the political acceleration of renewable energy transitions [J]. Energy Research & Social science, (2020) 67, 101-504.
[13] Yang Z B., Shao S., Yang g. Improment path way of energy consumption structctere in China's industrial sector: from the perspective of directed technical change [J]. Energy Economics, (2018) 72, 166-176.