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Exploring the Forms of the Economic Effects of Renewable Energy Consumption: Evidence from China

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Abstract: Renewable energy's economic effects have been hotly debated, as it is a promising energy source. However, scholars have not achieved an agreement on this hot topic. Therefore, this article re-examines the direct and indirect economic effects of renewable energy consumption in China from 1990 to 2020. Using the Granger causality test to conduct empirical analysis, the result suggests there is a bidirectional causality between renewable energy consumption and economic growth. Then, the mediation model is used for further analysis. The results suggest that economic growth is positively affected by renewable energy consumption. Meanwhile, renewable energy consumption can also indirectly affect economic growth through gross capital formation, the labor force, trade openness, research and development expenditure, and foreign direct investment. Based on the evidence this article provides, policymakers can issue corresponding policies to maintain sustainable economic growth while minimizing environmental pollution.

Keywords: renewable energy consumption; economic growth; Granger causality test; mediation model; paths

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1. Introduction

Non-fossil energy sources, such as wind, solar, hydro, and geothermal energy, are all examples of renewable energy. It is a sustainable form of energy. Yu et al. [1] considered it a crucial component of China's multi-wheel drive energy supply system, as it is non-polluting and low-carbon. Batel [2], Olabi and Abdelkareem [3], Dincer and Rosen [4], and Mahmood et al. [5] concluded that it was critical for developing energy infrastructure, conserving the environment, dealing with climate change, and achieving sustainable economic and social growth. China's Renewable Energy Development Report 2021 stated that China's renewable energy power production reached 221.48 billion kwh in 2020, up 8.4% from the previous year. In addition, by the end of 2020, China's installed capacity for renewable energy power production had reached 934 million KW, representing a 17.5% year-on-year growth. President Xi Jinping delivered a number of major addresses. He said unequivocally that China's carbon dioxide emissions should peak before 2030 and that China should aim for carbon neutrality by 2060. Non-fossil energy will account for about 25% of primary energy consumption by 2030, with wind and solar power output totaling more than 1.2 billion kilowatts. He also highlighted the strategic direction of China's energy transformation and reform and established a new aim for China's renewable energy growth. Based on the above analysis, it can be concluded that renewable energy plays an increasingly important role in China's sustainable economic and social development.

According to the China Renewable Energy Development Report, which was released in 2020, China's renewable energy needs to be significantly expanded to reach 60% of the International Energy Agency's net-zero scenario share by 2030. To provide a more intuitive picture of the development in China's renewable energy, Figure 1 depicts the renewable energy and legal carbon share of China's electricity generation in the net-zero scenario from 2000 to 2030.

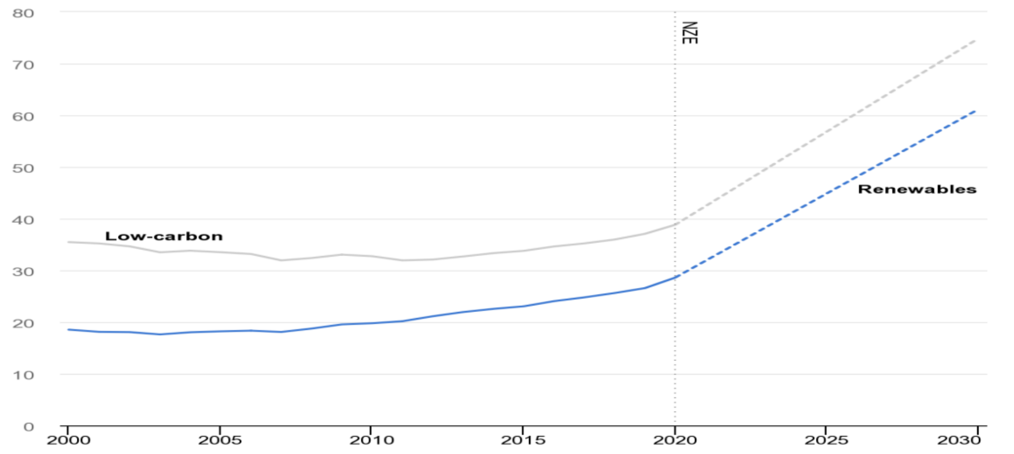

Figure 1. Renewable energy and low-carbon share in power generation in the net-zero scenario, 2000–2030.

In 2020, China's renewable electricity generation increased by 10%, with wind and solar photovoltaic technologies accounting for about 60% of this growth, a record annual increase by two percentage points. Nonetheless, the decline in electricity demand brought on by the COVID-19 slowdown in economic activity and mobility is a significant contributor to this record. To attain net-zero emissions by 2050, and a scenario share of more than 60 percent of generation by 2030, the deployment of China's renewable energy as a whole must still rise considerably. Moreover, compared with the rest of the world, such as Europe, China is building renewables at a faster rate. The comparison results are shown in Figure 2.

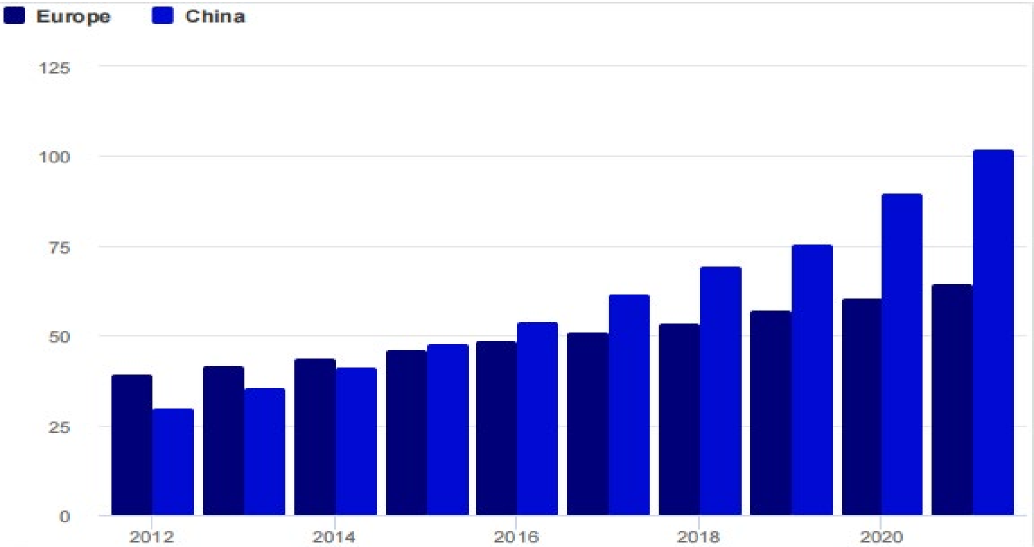

Figure 2. Renewable capacity, megawatt.

Indeed, numerous academics have employed a variety of approaches and samples to investigate the potential implications of renewable energy from diverse perspectives. Ocal and Aslan [6] used the auto-regressive distributed lag method and the Toda–Yamamoto causality test to explore the effect of renewable energy consumption on economic growth in Turkey. They found that renewable energy consumption negatively affected economic growth. Meanwhile, they also found a unidirectional causality running from economic growth to renewable energy consumption. Aydin [7] used 26 OECD countries as a case to study the causality between renewable energy consumption and economic growth. Employing the Croux and Reusens test for empirical analysis, he found that a bidirectional permanent and temporary causality existed. Moreover, Koengkan et al. [8] used the Southern Common Market as an example to study this topic. Using the panel error correction model to conduct empirical analysis, they found that there was a long-run and short-run relationship between renewable energy consumption and economic growth. However, in Italy, Magazzino [9] found a unidirectional causality running from renewable energy consumption to economic growth using the Toda–Yamamoto approach for analysis. Using different methods, time spans, and countries, Grabara et al. [10], Khan et al. [11], and Banday and Aneja [12] also found the above results.

However, few previous studies have concerned the direct and indirect effects of renewable energy consumption on economic growth. As a result, the purpose of this paper is to study the direct and indirect economic effects of renewable energy consumption. Using the Granger causality approach and the mediation model to perform empirical analysis, we confirm the bidirectional causality between renewable energy consumption and economic growth. Meanwhile, the direct and positive effect of renewable energy consumption on economic growth is also re-verified. Furthermore, the indirect effect of renewable energy consumption on economic growth is found. Specifically, renewable energy consumption indirectly affects economic growth via the mediators of gross capital formation, the labor force, trade openness, research and development expenditure, and foreign direct investment. These results might provide new insights into studying the economic effects of renewable energy consumption.

Compared with the previous literature, this paper has made two contributions, in the following ways: Firstly, China is the world's second-largest economy and a major consumer of energy. It is more representative to discuss the economic implications of renewable energy consumption using China as an example. Secondly, the previous literature has discussed the long-term and short-term relationships between renewable energy consumption and economic growth. However, this paper explores the indirect effect of renewable energy consumption on economic growth along five paths (gross capital formation, labor force, trade openness, research and development expenditure, and foreign direct investment). In conclusion, these two contributions may enrich the existing literature.

2. Literature Review

Environmental deterioration has resulted from an over-reliance on fossil-fuel usage to develop economies. Therefore, renewable energy consumption has become the goal of all governments. Of course, the economic effect of renewable energy consumption has piqued the curiosity of many academics. They have not come to a cohesive conclusion, despite studying the issue in numerous countries, using different approaches and throughout different time periods. This section will explore the economic consequences of renewable energy consumption from the world's and Chinese perspectives.

2.1. Analysis of Economic Effects of Renewable Energy Consumption across the World

According to one school of thought, renewable energy consumption has no significant economic effect. Ozcan and Ozturk [13] examined the association between renewable energy consumption and economic development in 17 rising nations from 1990 to 2016. They used the bootstrap panel causality test developed by Kónya [14] for empirical study. They found that there was no causality running from renewable energy consumption to economic growth. Similarly, Rasoulinezhad and Saboori [15], Yildirim et al. [16], and Dogan [17] held the same view. Meanwhile, Bhat [18] used a neoclassical aggregate production and stochastic impacts by regression on population, affluence, and technology modeling framework to investigate the relationship between disaggregated energy consumption and economic growth in five countries from 1992 to 2016. He used robust unit root, cointegration, and long-run elasticity estimation approaches, such as pooled mean group and the differenced panel generalized method of moments. He found that renewable energy consumption could not affect economic growth. Moreover, these ideas were also supported by Zhe et al. [19], Hung-Pin [20], and Xiarchos et al. [21].

Another group of scholars discovered that renewable energy consumption has a considerable influence on economic growth. Ito [22] attempted to objectively investigate the relationship between renewable energy consumption and economic development using panel data from 42 industrialized countries from 2002 to 2011. He discovered that renewable energy consumption had a long-run favorable impact on economic growth. Meanwhile, Rahman and Velayutham [23] examined the link between renewable energy consumption and economic growth for five countries from 1990 to 2014. Using the Pedroni [24] and Kao [25] tests and the Dumitrescue–Hurlin [26] panel causality test to perform empirical analysis, they found that economic growth was positively affected by renewable energy consumption. Similarly, Cetin [27], Le et al. [28], Narayan and Doytch [29], Sahlian et al. [30], and Shahbaz et al. [31] found the same results. However, Maji et al. [32] employed panel dynamic ordinary least squares to evaluate the influence of renewable energy on economic development in West African countries during the period 1995–2014. They discovered that renewable energy consumption hindered economic development in these countries. Simultaneously, Qi and Li [33] and Venkatraja [34] obtained the conclusion that the economic effect of renewable energy consumption was negative. Of course, some other scholars [35–37] also supported these findings.

Except for the above analyses, Shakouri and Khoshnevis Yazdi [38] investigated the links between economic growth and renewable energy consumption in South Africa from 1971 to 2015. They discovered that there was a bidirectional relationship between renewable energy consumption and economic development. The feedback theory was validated by this finding. Apergis and Payne [39], Apergis and Payne [40], and Marinașet al. [41] also agreed with these results. On the contrary, with a sample of Tunisians from 1990 to 2015, Ben Mbark et al. [42] used the Granger causality test and a vector error correction model to uncover the short- and long-run relationships between renewable energy consumption and economic growth. In the short term, they discovered a unidirectional relationship between both of them. Furthermore, Kahia et al. [43] investigated the relationship between economic development and energy consumption in two samples of MENA net oil exporting nations from 1980 to 2012. They found a unidirectional causality between economic growth and renewable energy consumption. These findings were also in line with Saad and Taleb [44], Azam et al. [45], Cho et al. [46], and Xie et al. [47].

2.2. Analysis of the Economic Effects of Renewable Energy Consumption in China

For a long time, China's economic growth mode was based on the use of fossil fuels, which resulted in environmental degradation. In order to preserve sustainable economic development, a number of academics started to investigate alternatives to fossil fuels. For the period 1977–2011, Lin and Moubarak [48] examined the link between renewable energy consumption and economic growth. By integrating intermittent variables such as carbon dioxide emissions and labor, the autoregressive distributed lag method, Johansen cointegration approach and Granger causality were used. They found a bidirectional causality between renewable energy consumption and economic growth. In other words, China's growing economy was favorable for renewable energy development, which, in turn, supported economic growth. Meanwhile, Long et al. [49] incorporated nonrenewable energy and carbon dioxide emissions and used the data from 1952 to 2012 to study this topic. Via a Granger causality analysis, they also found a bidirectional causality between economic growth and gas consumption, and electricity consumption. Similarly, Bloch et al. [50] conducted empirical research using both the vector error correction model and autoregressive distributed lag approach. They discovered that renewable energy consumption drove economic growth. Meanwhile, economic expansion increased demand for renewable energy. However, Dong et al. [51] used the Granger causality of vector error correction model for analysis. They found that there was no causality between economic growth and renewable energy consumption. Moreover, this results were supported by Zhang et al. [52], Zhang and Da [53], and Fei et al. [54].

Chen et al. [55] used the fully modified ordinary least squares, dynamic ordinary least squares, and panel Granger causality to examine how economic growth and renewable energy consumption affected each other. They found that there was a bidirectional causality between renewable energy consumption and economic growth. Using Chinese provincial data from 2000 to 2015, Fan and Hao [56] employed the panel vector error-correction model and Granger causality for analysis. They found that economic growth could cause renewable energy consumption, while renewable energy consumption could not cause economic growth. Using unique Morlet wavelet analysis, Arain et al. [57] offered a new understanding of the robust relationship between renewable energy consumption and economic growth. According to wavelet analysis's economic perspective, they found that renewable energy consumption contributed to the improvement in China's economy. Wang et al. [58] used the panel autoregressive distributed lag of pooled mean group model to investigate the link between economic growth and renewable energy consumption in China at the national and regional levels from 1997 to 2017. They found that economic growth was positively affected by renewable energy consumption. Wang and Wang [59] discovered that higher renewable energy consumption had a favorable influence on economic development, implying that greater renewable energy consumption contributed to economic growth. These results are also consistent with Pao and Fu [60]. Furthermore, these findings were supported by Li et al. [61], Zhang et al. [62], Zhang and Cheng [63].

Based on the examination of this literature, it is clear that experts have not achieved an agreement on the economic implications of renewable energy consumption. As a result, this work uses China as a case study to revisit this proposition from 1990 to 2020. The findings of this work support the feedback hypothesis of the relationship between renewable energy consumption and economic growth. In addition, the findings of this work also identify five indirect forms of the economic effect of renewable energy consumption. This new evidence may enrich the current literature.

3. Variable Description and Model Specification

3.1. Variable Description

This subsection outlines the variables that are highlighted in this study. This study chose the following variables to better portray the economic impacts of renewable energy consumption:

Dependent variable: Gross domestic product is not only the primary indicator of national economic accounting, but it is also a fundamental indicator for assessing a country's or religion's economic position and degree of development. This means that, in this study, economic growth is used as a proxy for economic effect. This approach was also supported by Salim et al. [64], and Dogan [65].

Independent variable: Wind energy, solar energy, hydro energy, and geothermal energy are examples of renewable energy. Renewable energy is non-polluting and low-carbon energy. It is a critical component of China's multi-wheel drive energy supply system. It is fundamental to strengthening energy infrastructure, safeguarding the environment, dealing with climate change, and achieving sustainable economic and social growth. This indicates that, in this study, renewable energy consumption is used to explore its economic effects.

Mediating variable: There are a multitude of mediating variables that may be deduced from the antecedents of behavior and the ultimate behavior outcome itself, but cannot be directly seen between the stimulation of renewable energy consumption and its economic consequences. As a result, following Gyimah et al. [66], Khan et al. [67], Zahoor et al. [68], and Sebri [69], this study selects gross capital formation, labor force, trade openness, research and development expenditure, and foreign direct investment as proxies for mediator variables to explore the indirect economic effects of renewable energy consumption on economic growth.

The variables used in this paper are listed in Table 1 for readability and comprehension by the readers.

Table 1. Variable description.

Variable	Form	Definition	Source
Renewable energy consumption	ren	Renewable energy consumption is the share of renewable energy in total final energy consumption in log.	World Bank
Economic growth	eco	Annual percentage growth rate of gross domestic product based on constant 2015 in log.	World Bank
Gross capital formation	gro	Gross capital formation is the share of gross domestic product in log.	World Bank
Labor force	lab	Labor force participation rate, total (% of total population ages 15–64) in log.	World Bank
Trade openness	tra	Trade is the sum of exports and imports of goods and services measured as a share of gross domestic product in log.	World Bank
Research and development expenditure	tec	Research and development expenditure (% of gross domestic product) in log.	World Bank
Foreign direct investment	for	Net inflows (% of gross domestic product) in log.	World Bank

3.2. Model Specification

The previous literature has employed various approaches to examine the economic effects of renewable energy consumption. However, the indirect role played by these investigated variables in strengthening the economic effects of renewable energy consumption has not received the recognition it needs, according to the literary work we investigated. As a result, this failure needed to be addressed in order to identify the connection and recognize indirect and direct functions performed by the investigated variables in the work. Studies such as Blinder et al. [70], Banerjee et al. [71], Hylleberg and Mizon [72], and Hjalmarsson and Österholm [73] were thoroughly evaluated in reaching a reliable conclusion in the work. The mediation model and Granger causality are used in this work to verify Lu's [74] analysis of the direct and indirect economic effects of renewable energy consumption. Before performing the cointegration test, we determined if the investigated variables were stationary or not. Then, we tested for cointegration between these investigations and sought to confirm their causality. Furthermore, for the purposes of path analysis, we investigated the connection between the investigated variables. Meanwhile, we came to a conclusion by applying the mediation model to determine the path directions. The baseline regression model is shown as follows:

$$eco_t = a_1 + a_2ren_t + a_3gro_t + a_4lab_t + a_5tra_t + a_6tec_t + a_7for_t + w_t, \quad (1)$$

where t denotes year; a_1 denotes constant; [a_2, a_7] denote estimated coefficients; and w_t white noise.

$$ren_t = b_1 + b_2eco_t + b_3gro_t + b_4lab_t + b_5tra_t + b_6tec_t + b_7for_t + w_{t1}, \quad (2)$$

where b_1 denotes constant; [b_2, b_7] denote estimated coefficients; and w_{t1} white noise.

$$gro_t = c_1 + c_2ren_t + c_3eco_t + c_4lab_t + c_5tra_t + c_6tec_t + c_7for_t + w_{t2}, \quad (3)$$

where c_1 denotes constant; $[c_2, c_7]$ denote estimated coefficients; and w_{t2} white noise.

$$lab_t = d_1 + d_2ren_t + d_3gro_t + d_4eco_t + d_5tra_t + d_6tec_t + d_7for_t + w_{t3}, \quad (4)$$

where d_1 denotes constant; $[d_2, d_7]$ denote estimated coefficients; and w_{t3} white noise.

$$tra_t = e_1 + e_2ren_t + e_3gro_t + e_4lab_t + e_5eco_t + e_6tec_t + e_7for_t + w_{t4}, \quad (5)$$

where e_1 denotes constant; $[e_2, e_7]$ denote estimated coefficients; and w_{t4} white noise.

$$tec_t = f_1 + f_2ren_t + f_3gro_t + f_4lab_t + f_5tra_t + f_6eco_t + af_7for_t + w_{t5}, \quad (6)$$

where f_1 denotes constant; $[f_2, f_7]$ denote estimated coefficients; and w_{t5} white noise.

$$for_t = g_1 + g_2ren_t + g_3gro_t + g_4lab_t + g_5tra_t + g_6tec_t + g_7eco_t + w_{t6}, \quad (7)$$

where g_1 denotes constant; $[g_2, g_7]$ denote estimated coefficients; and w_{t6} white noise.

From model (1) to model (7), the independent variable's indirect and direct effects on dependent variable is examined [75]. In addition, in order to explain the relationship between these variables and the models, Figure 3 is provided.

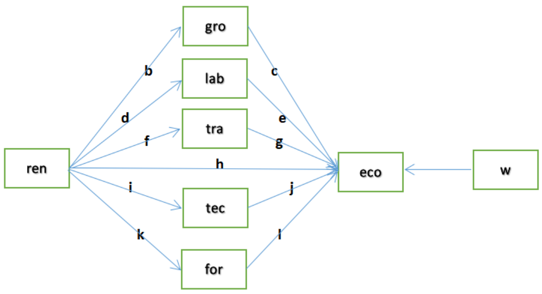

Figure 3. Schematic diagram of the mediation model. Direct effect: **h**; indirect effects: **b*c**, **d*e**, **g*f**, **i*j**, and **k*l**.

4. Results and Discussion

4.1. Variables' Statistical Description

The objective of this subsection is to perform a basic statistical analysis on the variables under investigation in this article in order to have a better understanding of them. The mean, maximum, minimum, and standard deviation are all included in these statistical studies. The results are shown in Table 2.

Table 2. Results of variables' statistical description.

var/sta	ren	eco	gro	lab	tra	tec	for
mean	1.285	0.936	1.606	1.902	1.612	0.153	0.473
max	1.5323	1.153	1.669	1.926	1.809	0.707	0.791
min	1.055	0.371	1.526	1.880	1.385	−1.000	0.029
std	0.187	0.159	0.045	0.018	0.109	0.312	0.216

Note: var variable; sta statistics; max maximum; min minimum; std standard deviation.

Table 2 shows that renewable energy consumption has a mean value of 1.285 and a standard deviation of 0.187. This means that China's renewable energy consumption accounts for an increasing proportion of total energy consumption. However, it fluctuates greatly. This outcome is also consistent with China's real situation. One probable explanation is that, in addition to focusing on fast economic expansion, China has started to prioritize environmental conservation for sustainable development. Economic growth has a mean value of 0.936 and a standard deviation of 0.159. This implies the sustainable growth in China's economy. However, its standard deviation also illustrates the serious fluctuations in China's economy. One possible reason is that China prioritizes the quality of economic growth above quantity. The other possible reason is unstable factors abroad. Gross capital formation has a mean value of 1.606 and a standard deviation of 0.045. Labor force has a mean value of 1.902 and a standard deviation of 0.018. These two statistics imply that the labor force continues to play an essential in China's economic growth. That is, China's economic growth mode is labor-intensive. Trade openness has a mean value of 1.612 and a standard deviation of 0.109. This indicates that the integration of China's economy into the global economy is progressing. Research and development expenditure has a mean value of 0.153 and a standard deviation of 0.312. This indicates that the research and development expenditure has an increasing trend. Foreign direct investment has a mean value of 0.473 and a standard deviation of 0.216. This indicates that foreign direct investment is also increasing but fluctuating significantly.

4.2. Fundamental Statistical Analysis

The objective of this subsection is to perform fundamental statistical tests of the variables investigated in this paper. They include the unit root test, the cointegration test, and the correlation test. The results are shown in Table 3.

Table 3. Results of fundamental statistical analysis.

	ren	**eco**	**gro**	**lab**	**tra**	**tec**	**for**
Pane A: Unit Root Test							
ADF-test (level)	−1.545 (0.113)	−0.501 (0.491)	0.338 (0.776)	0.476 (0.812)	0.532 (0.825)	−1.578 (0.106)	−0.642 (0.431)
PP-test (level)	−2.192 (0.029)	−0.522 (0.482)	0.769 (0.874)	0.816 (0.953)	0.373 (0.786)	−1.744 (0.101)	−0.683 (0.413)
	Δren	Δeco	Δgro	Δlab	Δtra	Δtec	Δfor
ADF-test (first difference)	−2.347 (0.021)	−3.232 (0.002)	−3.609 (0.001)	−4.586 (0.000)	−3.686 (0.001)	−7626 (0.000)	−4.387 (0.000)
PP-test (first difference)	−2.235 (0.027)	−3.232 (0.002)	−3.549 (0.001)	−4.640 (0.000)	−3.667 (0.001)	−10.303 (0.000)	−4.299 (0.000)
Panel B: Cointegration test							
	Trace statistics		Critical value 5%		Max-eigen value	Critical value 5%	
r = 0	179.444		125.615		58.542	46.231	
r ≤ 1	120.901		95.753		45.004	40.077	
r ≤ 2	75.897		69.819		25.965	33.877	
r ≤ 3	49.932		47.856		20.421	27.584	
r ≤ 4	29.510		29.797		16.487	21.132	
r ≤ 5	13.023		15.495		11.585	14.264	
r ≤ 6	1.438		3.842		1.438	3.841	
Panel C: Correlation test							
	ren	eco	gro	lab	tra	tec	for
ren	1.000						
eco	0.278	1.000					
gro	0.847	0.024	1.000				
lab	0.985	0.284	−0.796	1.000			
tra	0.531	0.392	0.474	−0.554	1.000		
tec	0.417	0.233	0.633	−0.377	0.244	1.000	

for	0.303	0.706	−0.095	0.339	0.435	0.141	1.000

Note: *p*-value shown in the parentheses; Δ difference operator.

Table 3 shows the results of the unit root test in Panel A, the cointegration test in Panel B, and the correlation test in Panel C. In Panel A, the ADF test and PP test are used to determine if the variables under consideration in this paper are stationary. The results suggest that the variables have unit roots at their levels. That is, they are not stationary at their levels. On the contrary, the results also suggest that the variables do not have unit roots at their first difference. In other words, they are stationary on their first difference. As a result, it is essential to investigate the long-run equilibrium relationship between the highlighted variables in this paper. Then, the Johansen and Juselius [76] approach is used to determine the number of cointegrations.

The results of the cointegration test are shown in Panel B. For r = 0, the trace statistics are greater than the critical value of 5% (179.444 > 125.615), and the maximum exigen-value is greater than the critical value of 5% (58.542 > 46.231). These outcomes imply that the null hypothesis (no cointegration) is rejected, namely, the long-run equilibrium relationship between the highlighted variables. For r ≤ 1, the trace statistics are greater than the critical value of 5% (120.901 > 95.753), and the maximum exigen-value is greater than the critical value of 5% (45.004 > 40.077). These outcomes suggest there is one cointegration among the highlighted variables. For r ≤ 2, the trace statistics are greater than the critical value of 5% (75.897 > 69.819). However, the maximum exigen-value is greater than the critical value of 5% (25.965 > 33.877). These outcomes imply that the null hypothesis (no cointegration) is not rejected. Then, it can be concluded that one cointegration exists among the highlighted variables in this paper.

The correlation test was carried out to preliminarily judge the correlation between the highlighted variables. The panel displays the correlation test results. It can be seen that the correlation between renewable energy consumption and economic growth is positive. Meanwhile, it can also be found that gross capital formation, labor force, trade openness, research and development expenditure, and foreign direct investment are positively related to renewable energy consumption. Furthermore, economic growth is also positively related to cross capital formation, labor force, trade openness, research and development expenditure, and foreign direct investment.

4.3. Causality Analysis

As the results of Table 3 in Panel B suggest, there is a cointegration among the highlighted variables in this paper. Engle and Granger [77] found that it might be bidirectional or unidirectional causality if the result suggests a cointegration among the highlighted variables. Following Asiedu et al. [78], and Lee [79], a pairwise Granger causality test was conducted to explore the causality between the highlighted variables. The results are shown in Table 4.

Table 4. Results of causality analysis.

Null Hypothesis	F-Value	*p*-Value	Null Hypothesis	F-Value	*p*-Value
eco ≠ ren	7.239	0.012 **	gro ≠ eco	2.864	0.088 *
ren ≠ eco	7.069	0.018 **	eco ≠ gro	0.695	0.508
gro ≠ ren	1.742	0.196	lab ≠ eco	4.380	0.027 **
ren ≠ gro	4.143	0.028 *	eco ≠ lab	0.108	0.897
lab ≠ ren	9.926	0.001 ***	tra ≠ eco	2.851	0.077 *
ren ≠ lab	6.979	0.004 ***	eco ≠ tra	0.126	0.881
tra ≠ ren	3.624	0.042	tec ≠ eco	4.474	0.024 **
ren ≠ tra	1.675	0.208	eco ≠ tec	0.674	0.518
tec ≠ ren	0.660	0.525	for ≠ eco	9.507	0.001 ***
ren ≠ tec	1.285	0.294	eco ≠ for	1.717	0.201

for ≠ ren	0.048	0.952	lab ≠ gro	3.989	0.032 **
ren ≠ for	7.031	0.004 ***	gro ≠ lab	0.045	0.955
tra ≠ gro	0.394	0.678	tec ≠ gro	2.718	0.086 *
gro ≠ tra	4.112	0.029 **	gro ≠ tec	3.154	0.061 *
for ≠ gro	3.412	0.049 **	tra ≠ lab	0.703	0.505
gro ≠ for	4.585	0.021 **	lab ≠ tra	9.519	0.001 ***
tec ≠ lab	0.355	0.704	for ≠ lab	0.691	0.510
lab ≠ tec	1.624	0.218	lab ≠ for	7.232	0.004 ***
tec ≠ tra	1.525	0.237	for ≠ tra	0.140	0.870
tra ≠ tec	0.133	0.875	tra ≠ for	0.961	0.396
for ≠ tec	3.866	0.035 **	tec ≠ for	2.273	0.124

Note: ≠ does not cause; * 10% significant level; ** 5% significant level; *** 1% significant level.

Table 4 presents the results of causality between the highlighted variables. A feedback causality between economic growth and renewable energy consumption is found. That is, economic growth causes renewable energy consumption, while renewable energy consumption causes economic growth. This finding is consistent with Alam and Murad [80], who found that, in twenty-five OECD countries, expanding renewable energy consumption boosted economic growth. Moreover, this outcome is also supported by Lin and Moubarak [64], who found a bidirectional causality between economic growth and renewable energy consumption from 1977 to 2011. The usage of and development in solar and mini-grids as components of a country's plan to increase renewable energy consumption also boosted economic growth. Of course, this outcome is also supported by other previous literature, such as Ocal and Aslan [65], Shahbaz et al. [31], and Sebri and Ben-Salha [81]. In addition, this outcome remains in line with China's real situation. Specifically, China's fast economic expansion needs a high level of energy consumption as a foundation. At the same time, increasing amounts of energy use will cause environmental deterioration, so demand for renewable energy will rise to compensate for the environmental damage.

Moreover, gross capital formation, labor force, and research and development expenditure significantly cause economic growth. These results are consistent with Topcu et al. [82], Hicks et al. [83], and Zafar et al. [84]. This implies that, at present, gross capital formation, labor force, and research and development expenditure are important drivers for promoting China's economic growth. Certainly, these outcomes are in line with the actual situation in China, which is the world's largest developing economy. Meanwhile, trade openness and foreign direct investment also significantly contribute to economic growth. These outcomes are consistent with Chen et al. [85], Pilinkiene [86], and Ostic et al. [87]. A possible explanation is that, because of China's overcapacity, a substantial quantity of excess capacity is exported overseas. The other explanation is that China spares no effort in helping the "One Road, One Belt" countries carry out a lot of infrastructure construction, which has led to a rapid increase in China's foreign direct investment.

4.4. Indirect and Direct Economic Effects of Renewable Energy Consumption

Following Williams et al. [88] and Wang and Lee [89], the objective of this subsection is to explore the indirect and direct economic effects of renewable energy consumption. The results are shown in Table 5.

Table 5. Results of indirect and direct economic effects of renewable energy consumption.

Direct Effect		Indirect Effect	
ren → gro	0.205 *** (8.581)	ren → gro → eco	0.018
ren → lab	0.094 *** (9.413)	ren → lab → eco	0.024
ren → tra	0.309 *** (3.372)	ren → tra → eco	0.177
ren → tec	0.694 ** (2.471)	ren → tec → eco	0.083
ren → for	0.349 * (1.713)	ren → for → eco	0.182
ren → eco	0.237 *** (3.197)		
gro → eco	0.087 *** (3.296)		
lab → eco	0.252 *** (5.934)		
tra → eco	0.573 ** (2.297)		
tec → eco	0.119 *** (2.891)		
for → eco	0.522 *** (5.375)		

Note: t-statistics shown in the parentheses; → path; * 10% significant level; ** 5% significant level; *** 1% significant level.

In Table 5, the indirect and direct economic effects of renewable energy consumption are presented. It can be found that the effect of renewable energy consumption on economic growth is positive and significant. In this paper, gross capital formation, labor force, trade openness, R&D expenditure, and foreign direct investment are used as mediators. Meanwhile, the table's findings suggest that gross capital formation, labor force, trade openness, R&D expenditure, and foreign direct investment are all indicators of GDP. These outcomes are consistent with Ntamwiza and Masengesho [90], Islam et al. [91], Usman et al. [92], Boeing et al. [93], and Iqbal et al. [94]. Furthermore, we also find that renewable energy consumption can indirectly affect economic growth via five kinds of channels. The paths are renewable energy consumption → gross capital formation → economic growth, renewable energy consumption → labor force → economic growth, renewable energy consumption → trade openness → economic growth, renewable energy consumption → research and development expenditure → economic growth, and renewable energy consumption → foreign direct investment → economic growth. These findings are different from previous literature such as Zafar et al. [95], Iqbal et al. [94], and Chen et al. [85], who only analyzed the long-run or short-run effect of renewable energy consumption on economic growth.

5. Conclusions

The purpose of this paper is to explore the indirect and direct effects of renewable energy consumption on economic growth. Using data from 1990 to 2020 for empirical study, the findings of the Granger causality test reveal that a feedback relationship between renewable energy consumption and economic growth is found. The findings confirm the feedback theory that economic growth and renewable energy are inextricably linked [46]. Gross capital formation, labor force, trade openness, research and development expenditure, and foreign direct investment positively affect economic growth. Moreover, the findings demonstrate that the investigated variables have a long-run effect on economic growth. Then, the mediation model was used to corroborate the above conclusion. Meanwhile, the indirect effect of renewable energy consumption on economic growth was also examined. The results suggest that renewable energy consumption positively affects gross capital formation, labor force, trade openness, research and development expenditure, and foreign direct investment (proxies for mediator variables). Simultaneously, these mediator variables have positive effects on economic growth. To this end, it can be found that renewable energy consumption can indirectly affect economic growth via gross capital formation, labor force, trade openness, research and development expenditure, and foreign direct investment.

Appropriate policy recommendations can be made based on the empirical findings of this article. Firstly, because of the positive economic effects of renewable energy consumption, the Chinese government should accelerate renewable energy to replace non-renewable energy, which would help economic growth while also improving environmental quality. Secondly, since renewable energy consumption has a favorable indirect influence on economic development through gross capital formation, labor force, trade openness, research and development expenditure, and foreign direct investment, the Chinese government should increase gross capital formation, employment rate, research and development expenditure, and expand foreign direct investment. Thirdly, as for the methodology implications, the approach in this paper can be used to analyze the economic effects of renewable energy consumption for those countries with similar characteristics to China. Russia, Brazil, India, and South Africa are all good examples. Their conventional economic development strategy, like China's, is based on fossil fuels. As the detrimental effect of fossil fuel use on environmental sustainability became apparent, these countries started to emphasize the use of renewable energy. As a result, the economic effects of renewable energy consumption in these countries are becoming more significant. To summarize, the study methodology used in this work may be applied to these countries when addressing the direct or indirect economic consequences of renewable energy consumption.

In addition, this study has some limitations. Future researchers may make use of these limitations to broaden their studies. First, this study investigates this issue using time-series data because of the large disparity in energy consumption and economic development patterns among eastern, central, and western areas. As a result, future researchers may revisit this subject using the panel data of Chinese provinces. Second, there are additional mediating variables such as environmental and social factors that were not examined in this work. Future researchers may incorporate these mediating factors into this work for empirical analysis. Different outcomes may be achieved by releasing these limitations. Third, the social consequences of renewable energy consumption are not addressed in this paper. Future researchers may use the results of this work to expand consideration of the subject in terms of social issues. The possible reason is that renewable energy sources have had a social impact through creating jobs, improving the quality of life in rural areas, improving health by decreasing pollutants, and boosting knowledge levels not just among professionals but also among the general public. In China, the introduction of renewable energy and the construction of related projects and enterprises over the last 30 years has created a source of employment for many citizens while avoiding a substantial quantity of pollution in the atmosphere. Wind farms and solar power plants have been installed in some Chinese provinces, and some metropolitan departments have used photovoltaic systems for public illumination. Future researchers may expand this topic by exploring the social effects of introducing these technologies related to renewable energy in several Chinese provinces, not only in the social area but also in the cultural, economic, environmental, and tourist domains. Fourth, when figuring out what the economic effects of renewable energy are, this paper cannot cover all of the contributing factors. Following Zaidi et al. [96], and Mungai et al. [97], future researchers may incorporate population growth, urbanization, financial inclusion, corruption, and infrastructure to re-study the economic effects of renewable energy. Fifth, following Banerjee [98], future researchers can discuss this topic from the industry level and with environmental regulation. This may produce more concrete and interesting results.

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