energies

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Does Information and Communication Technology Trade Openness Matter for China's Energy Transformation and Environmental Quality?

Yinhui Wang [1] and Yugang He [2,*]

[1] College of Commerce, Jeonbuk National University, Jeonju 54896, Republic of Korea
[2] Department of Chinese Trade and Commerce, Sejong University, Seoul 05006, Republic of Korea
* Correspondence: 1293647581@sejong.ac.kr

Abstract: Energy transformation and environmental quality are now fundamental components of China's economic development plans, which are being reorganized to ensure the dependability of the energy supply and protect environmental quality. Nonetheless, technical inefficiency is one of the most significant obstacles to achieving these overall objectives. Therefore, utilizing yearly data from 2000 to 2021 and the autoregressive distributed lag model, this article examines the implications of information and communication technology trade openness on China's energy transformation and environmental quality. The findings indicate that information and communication technology trade openness has a favorable impact on environmental quality as a consequence of its negative impact on carbon dioxide emissions. Moreover, the findings indicate that information and communication technology trade openness has a beneficial impact on energy transformation due to its positive impact on renewable energy consumption and negative impact on energy intensity. In conclusion, our findings demonstrate the necessity of eliminating obstacles to information and communication technology trade in China in terms of guaranteeing energy transformation and environmental quality. Therefore, it is optimal for China's government to progressively reduce trade barriers in order to increase cross-border flows of information and communication technology products.

Keywords: energy transformation; environmental quality; information and communication technology trade openness; autoregressive distributed lag model; renewable energy consumption; energy intensity; carbon dioxide emissions

Citation: Wang, Y.; He, Y. Does Information and Communication Technology Trade Openness Matter for China's Energy Transformation and Environmental Quality? *Energies* **2023**, *16*, 2016. https://doi.org/10.3390/en16042016

Academic Editors: Carmelina Cosmi and Senatro Di Leo

Received: 4 January 2023
Revised: 14 February 2023
Accepted: 16 February 2023
Published: 17 February 2023

1. Introduction

Since the reform and opening of China, the country has traditionally relied on the use of environmentally damaging non-renewable energy to satisfy its energy needs, which has ultimately sparked a consensus among Chinese academic circles on achieving socio-economic and environmental sustainability, particularly via optimal use of renewable energy alternative options. The consistent reliance on the combustion of non-renewable energy resources has contributed to the overexploitation of these limited resources, which in turn has put China's energy security issue in jeopardy to a significant degree [1,2]. Therefore, the transformation of energy sources has quickly risen to the top of China's list of urgent top priorities. In recent years, China's growth of renewable energy sources such as hydropower, wind energy, solar energy, and biomass energy has produced tremendous achievements [3]. According to information from China's National Bureau of Statistics, in 2021, China's renewable energy install capacity surpassed 1 billion kilowatts, ranking first in the world in terms of growth size. Hydropower, wind power, solar power production, and biomass power generation have been rated the top in the world for seventeen, twelve, seven, and four straight years, respectively [4]. China is not only able to independently develop and produce megawatt water turbines, ultra-high dams, and enormous subterranean caverns, but it has also accomplished fast iterations of solar technology in only a few years, surpassing the world record for battery conversion efficiency many times. In the industrial chain, China's wind power and other industries, leveraging their worldwide competitive advantages of "low cost and high technology", have progressively filled the high-end market in Europe, therefore driving the growth of global industries. China's PV module production has led the globe for 15 straight years, while its polysilicon production has led the world for 11 consecutive years [5].

China has achieved a number of accomplishments in the field of renewable energy, all of which demonstrate that China attaches great importance to the development of renewable energy sources such as solar energy, wind energy, and hydrogen energy, as well as its advanced concept of ecological civilization [6]. Faced with the energy supply crisis caused by geopolitical conflicts, some countries place a much greater emphasis on energy security than on energy transformation, whereas the Chinese government is fully aware that there is no contradiction between "ensuring energy security" and "achieving the dual carbon goals" and that there is a distinction between short-term and long-term goals, allowing for coordinated development. This understanding of the development of renewable energy from a more long-term perspective has prompted China to take comprehensive and targeted measures to actively promote energy transformation based on the characteristics of the various stages of renewable energy development. In addition to diminishing the likelihood of achieving energy security in the economy, the high use of nonrenewable resources is believed to have contributed to China's environmental deterioration. The release of more greenhouse gases into the atmosphere as a result of the combustion of these nonrenewable fossil fuels has contributed to the adverse effects of climate change [7–9]. As a result of this, the conversion of renewable energy is seen as a reliable method for reducing the emissions of environmental pollutants that result from the burning of non-renewable resources [10–12]. The transition away from the use of fossil fuels in China's economy is connected to China's increasing reliance on renewable energy sources [13–15]. The transition from fossil fuels to renewable energy may lower carbon dioxide emissions, the primary greenhouse gas driving climate change problems. Therefore, renewable energy technology is regarded as a necessity for China's energy transformation and environmental quality.

In the United Nations' Sustainable Development Goals proclamation, the crucial responsibilities of renewable energy transformation in reducing global energy problems and promoting environmental quality were also emphasized. The seventh goal of the seventeen Sustainable Development Goals is to approach a worldwide pledge to increase reliable, sustainable, modern, and affordable supply globally by considerably expanding renewable energy in total global final energy consumption and, at the same time, doubling the efficiency of energy use by 2030, and by adopting renewable energy technologies in lieu of walking in parks, especially in developing economies. Bhattarai et al. [13], Luthra et al. [14], and Timilsina et al. [15] stated that the technical limitations faced by developing nations were one of the primary factors impeding the adoption of renewable energy technology in these nations. In addition, Simpson et al. [16] and Usman et al. [17] claimed that redundant technologies impeded the adoption of renewable energy technology, particularly in low-income nations. Moreover, Uhunamure and Shale [18] and Hassan et al. [19] considered that inefficient technology impeded the preservation of renewable energy, rendering the incorporation of renewable energy into the energy mix a laborious endeavor. As a consequence of this, the lack of technological know-how has resulted in the creation of poor energy infrastructure in emerging countries, which has therefore delayed the transformation from the utilization of non-renewable energy sources to the utilization of renewable energy sources in these economies, such as China.

Because of the findings of this article, the body of knowledge has also been advanced as a consequence of these findings in the following three ways: first, in this investigation, a specific analysis of the consequences of broadening openness of trade in information and communication technologies is carried out to facilitate renewable energy technology, assess energy intensity, and reduce carbon dioxide emissions in China in order to ensure energy transformation and environmental quality. Despite the fact that a large number of earlier studies have examined the consequences of employing information communication technology goods such as Internet use, mobile services, and fixed broadband subscriptions, the impacts of liberalizing trade barriers that assert cross-border information communication technology goods flows have not yet been recorded in the published literature. Second, as far as we are aware, this is a brand-new study that covers the roles of information and communications technology trade in the context of China, as was said before. Third, it is being looked into whether or not there is a relationship between the openness of trade in information and communication technology and the indices of energy transformation and environmental quality that were discussed earlier in this article, both in the short term and the long term.

The remaining portions of this work are organized as follows: the literature review is presented in the second section. In the third section, variables and models are presented. The findings and a discussion are presented in the fourth section. Section five gives conclusions.

2. Literature Review

In this section, the emphasis is on the analysis of the past studies that have been conducted on the impacts of information and communication technology trade openness (CTO) on energy transformation and environmental quality with regard to samples, time spans, and techniques. This may give a framework for this inquiry that is both theoretical and objective.

Recognizing the capabilities of information and communication technology applications to use renewable energy sources results in the idea of liberalizing barriers to information and communication technology trade in order to increase the total volumes and proportions of renewable energy utilization in the trading economy. Eliminating trade barriers is expected to enhance cross-border flows of products and services from a nation with a comparative advantage in their production to a country with a comparative disadvantage. Yakubu et al. [20] evaluated how the rise in international trade of items related to information and communications technology affected China's progress toward a more renewable energy transformation over the period of 2000–2017. Specifically, using the dynamic least squares regression, they investigated the effects that information and communications technology trade might have over the long run on renewable energy. They observed that expanding trade in information and communications technology goods stimulated demand for renewable energy and mitigated environmental damage. This, in turn, supported China's clean energy program by providing support for China's clean energy initiatives. The trade of information and communications technology products in today's advanced economy is the root cause of a wide variety of adverse impacts on both the economy and the environment. However, the degree of regional development may influence the magnitude and nature of the consequences for the parties involved in the trade. Nejati and Shah [21] investigated the effects of international trade in information and communications technology goods on economies, environments, and energy intensities in both developing and developed nations. Their findings, which were based on an application of a dynamic, computable general equilibrium model, demonstrated that an increase in information and communications technology imports led to a decrease in energy intensity. In accordance with the Sustainable Development Goals and the recent COP26 conference, energy transformation, low carbon emissions, and technology have risen to the top of policymakers' agendas. Tzeremes et al. [22] used the unique GMM-PVAR approach that was presented to the annual data over the period 2000–2017 and analyzed the connection between energy transformation and information and communications technology in Brazil, Russia, India, China, and South Africa. Furthermore, these results have also been corroborated by He and Huang [23], Atsu et al. [24], He and Zhang [25], and Faisal et al. [26]. As a result, following the review of the relevant literature, we are in a position to propose the following hypothesis:

Hypothesis 1 (H1). *Energy transformation is promoted by the openness of trade in information and communication technology.*

The widening of trade in information and communications technology has played a role in the worsening of trade imbalances and the escalation of tensions between nations. It would be useful to do a comprehensive study of the possible carbon and economic effects of international trade in information and communications technology. During the period of 2000–2018, Zhou et al. [27] used multiregional input–output models to determine the degree to which, as well as the manner in which, the economic gains and carbon costs that were inherent in the trade of information and communications technology were unevenly distributed throughout the world's regions. They discovered that imports from information and communications technology resulted in lower emissions of carbon dioxide and an improvement in environmental quality. In the present period of greater digitization and clamor for environmental quality, information and communication technology have become crucial in the transition towards a society with lower levels of carbon emissions. Evans and Mesagan [28] applied dynamic heterogeneous panel models that were resilient to cross-sectional dependency to examine the moderating impacts of good regulation and governance on the link between information and communication technology trade and pollution for 31 African nations from 2000 to 2020. Without making any adjustments for cross-sectional dependency, they found that trade in information and communication technology led to an increase in both short-run and long-run pollution. On the other hand, Ma et al. [29] employed the dynamic autoregressive distributed lag technique to deal with this problem from 1987 to 2020 while they were looking at China. They discovered that the trade in information and communication technology had a negative influence on emissions of carbon dioxide in both the long run and the short run. Meanwhile, these findings have been further supported by Usman et al. [30], Higón et al. [31], Zhang et al. [32], Khan et al. [33], and Zhang and Liu [34]. As a consequence of this, and on the basis of our analysis of the relevant previous research, we are in a position to put forth the following hypothesis:

Hypothesis 2 (H2). *Environmental quality is enhanced by the openness of the information and communication technology trade.*

The corpus of knowledge on this subject has progressed in three distinct ways as a direct result of this article. This was found in an evaluation of the study that was discussed when compared with earlier studies that were studied above. First, this study conducts a specific analysis of the implications of expanding the openness of information and communication technology trade in order to support renewable energy technology, access energy intensity, and reduce carbon dioxide emissions in order to ensure energy transformation and environmental quality in China. Despite the fact that numerous previous studies have examined the effects of utilizing information communication technology goods such as Internet use, mobile services, and fixed broadband subscriptions, the effects of liberalizing trade barriers that demonstrate cross-border information communication technology goods and services flows have yet to be documented in the scientific literature. Second, as far as I am aware, this is a brand-new study that covers the roles of information and communications technology trade in the setting of China, as mentioned before. Third, an investigation is being conducted to determine whether there is a link between the openness of trade in information and communications technology and the aforementioned indices of energy transformation and environmental quality, both in the short term and the long term.

3. Variable Description and Model Specification

3.1. Variable Description

The objective of this subsection is to provide a description of the variable that was investigated for this article. Trade openness is the process by which a nation progressively lowers the limits on the import of foreign products and services, gives preferential trade treatment for imported goods and services, and supports market orientation. The World Trade Organization and its predecessor, the GATT, share the goal of furthering the openness of trade. Imports of information and communication technology products include computers and peripheral equipment, communication equipment, consumer electronic equipment, and electronic components (miscellaneous). Following Nath and Liu [35], Azam et al. [36], and Adeleye et al. [37], the ratio of information and communication technology goods imports to total goods imports is a proxy for the CTO. The process of decreasing reliance on fossil fuels and re-engineering whole systems to function on energy sources with lower carbon emissions is referred to as the "energy transition" [38]. In a broader sense, an energy transition is a substantial structural shift in an energy system's supply and consumption. The present shift to sustainable energy is primarily motivated by the need to eliminate global greenhouse gas emissions. As fossil fuels are the single largest source of carbon emissions, the 2015 Paris Agreement limits the amount that may be generated in order to maintain global warming below 1.5 degrees. Over seventy percent of the world's greenhouse gas emissions come from the energy sector, which includes transportation, heating, and industrial usage [39]. Wind energy and photovoltaic solar systems offer the most potential to combat climate change. Since the late 2010s, the switch to renewable energy has also been spurred by the fast-rising competitiveness of both solar and wind power [40]. Another reason for making the switch is to reduce the number of negative effects that the energy business has on the surrounding environment [41]. Therefore, following Capurso et al. [42], Derkenbaeva et al. [43], and Wahlund and Palm [44], both renewable energy consumption and energy intensity are proxies for the energy transition. Environmental quality refers to a collection of traits and characteristics of the environment, either globally or locally, as they affect humans and other species. It is a measurement of the state of an environment in relation to the needs of one or more species, as well as any human need or goal [45]. Environmental quality encompasses the natural environment as well as the constructed environment, including air, water purity or pollution, and noise, as well as the possible consequences that such features may have on physical and mental health [46]. Thus, following Alola and Kirikkaleli [47], Wada et al. [48], Tan et al. [49], and Charfeddine et al. [50], carbon dioxide emissions are a proxy for environmental quality. To assure the accuracy of the estimated findings, this study includes several control variables. Following Zhang and Zhou [51], Shahbaz et al. [52], and Salahuddin et al. [53], foreign direct investment is included in this article. Following Li et al. [54], González-Álvarez and Montañés [55], and Chen et al. [56], Economic growth is included in this article. Following Wang et al. [57], Liu et al. [58], and Xu et al. [59], urbanization is included in this article. In order to make it easier for readers to comprehend the variables that are discussed in this article, the essential information about these variables is shown in Table 1.

Table 1. Results of variable description.

Variable	Form	Definition
Renewable energy consumption	new	Ratio of renewable energy consumption to total energy consumption
Energy intensity	eni	Energy intensity level of primary energy (MJ/$2017 PPP GDP) in log
Carbon dioxide emissions	cde	Carbon dioxide emissions (billion tons) in log
Communication technology trade openness	cto	Ratio of information and communication technology goods imports to total goods imports
Economic growth	gro	GDP (constant 2015 US; unit: billion) in log
Urbanization	urb	Proportion of population in towns and cities to total population
Foreign direct investment	fdi	The ratio of actual amount of FDI in GDP

Note: all data from 2000 to 2021 used in this article is sourced from World Bank Indicator.

3.2. Model Specification

Prior to carrying out a regression analysis, a unit root test is required in order to guarantee that there will be no spurious regressions. Within the context of this paper, the Augmented Dickey–Fuller unit root test is used. The following is the procedure that is used for Augmented Dickey–Fuller unit root test inspection:

$$\Delta y_t = \gamma y_{t-1} + \sum_{i=1}^{p} \beta_i \Delta y_{t-i} + \mu_t \tag{1}$$

$$\Delta y_t = \gamma y_{t-1} + \alpha + \sum_{i=1}^{p} \beta_i \Delta y_{t-i} + \mu_t \tag{2}$$

$$\Delta y_t = \gamma y_{t-1} + \alpha + \delta t + \sum_{i=1}^{p} \beta_i \Delta y_{t-i} + \mu_t \tag{3}$$

where y denotes these variables under consideration; α denotes the constant; δ denotes time trend term; Δ denotes the difference operator; μ_t denotes the random disturbance term; γ denotes the regression coefficient.

In this article, the autoregressive distributed lag (ARDL) approach is employed. This choice was made in accordance with the findings of Rasoulinezhad et al. [60], He et al. [61], and Udemba and Tosun [62]. One of the benefits of using this approach is that it does not require maintaining all variables at their current levels of stability. It can be used on the condition of I(0), I(1), or a mix of I(0) and I(1). In fact, Charemza and Deadman [63] were the ones who came up with the idea in the first place. In later years, Pesaran et al. [64] worked on polishing and enhancing it further [65]. However, before proceeding, the autoregressive distributed lag assessment must establish whether or not a stable association exists. The boundary test technique is mostly used in order to ascertain whether or not such a stable connection exists. If there is a connection, the correlation coefficient will be tested further. The objective of this article is to evaluate the impact of CTO on China's energy transformation and environmental quality using the analysis presented above. Then, the baseline models are presented as follows:

$$new_t = a_0 + a_1 cto_t + a_2 gro_t + a_3 urb_t + a_4 fdi_t + \mu_{1t}, \tag{4}$$

$$eni_t = b_0 + b_1 cto_t + b_2 gro_t + b_3 urb_t + b_4 fdi_t + \mu_{2t}, \tag{5}$$

$$cde_t = c_0 + c_1 cto_t + c_2 gro_t + c_3 urb_t + c_4 fdi_t + \mu_{3t}, \tag{6}$$

where a_0, b_0, and c_0 denote the constant; μ_{1t}, μ_{2t}, and μ_{3t} denote the white noise; $[a_1, c_4]$ denote the estimated coefficients. Upon determining the stationarity of variables, the ARDL bound test-based cointegration method yields:

$$\begin{gathered}\Delta new_t = e_0 + e_1 cto_{t-1} + e_2 gro_{t-1} + e_3 urb_{t-1} + e_4 fdi_{t-1} + \\ \sum_{j=1}^{n} e_{4t-1j} \Delta new_{t-j} + \sum_{j=1}^{n} e_{t-2j} \Delta cto_{t-j} + \sum_{j=1}^{n} e_{t-3j} \Delta gro_{t-j} + \sum_{j=1}^{n} e_{t-4j} \Delta urb_{t-j} + \\ \sum_{j=1}^{n} e_{t-5j} \Delta fdi_{t-j} + \mu_{4t},\end{gathered} \tag{7}$$

$$\begin{gathered}\Delta eni_t = f_0 + f_1 cto_{t-1} + f_2 gro_{t-1} + f_3 urb_{t-1} + f_4 fdi_{t-1} + \sum_{j=1}^{n} f_{5t-1j} \Delta eni_{t-j} + \\ \sum_{j=1}^{n} f_{t-2j} \Delta cto_{t-j} + \sum_{j=1}^{n} f_{t-3j} \Delta gro_{t-4j} + \sum_{j=1}^{n} f_{t-4j} \Delta urb_{t-j} + \sum_{j=1}^{n} f_{t-5j} \Delta fdi_{t-j} + \mu_{5t},\end{gathered} \tag{8}$$

$$\begin{gathered}\Delta cde_t = g_0 + g_1 cto_{t-1} + g_2 gro_{t-1} + g_3 urb_{t-1} + g_4 fdi_{t-1} + \sum_{j=1}^{n} g_{t-j} \Delta cde_{t-i} + \\ \sum_{j=1}^{n} g_{t-j} \Delta cto_{t-j} + \sum_{j=1}^{n} f_{t-3j} \Delta gro_{t-4j} + \sum_{j=1}^{n} f_{t-4j} \Delta urb_{t-j} + \sum_{j=1}^{n} f_{t-5j} \Delta fdi_{t-j} + \mu_{6t},\end{gathered} \tag{9}$$

where e_0, f_0, and g_0 denote the constant; μ_{4t}, μ_{5t}, and μ_{6t} denote the white noise. According to Equations (7)–(9), the following hypothesis is examined using the Wald test based on F-statistics to determine whether or not cointegration holds true. The null hypothesis gives: $H_o = e_1 = e_2 = e_3 = e_4 = 0$; $H_o = f_1 = f_2 = f_3 = f_4 = 0$; $H_o = g_1 = g_2 = g_3 =$

$g_4 = 0$. On the contrary, the alternative hypothesis gives: $H_o \neq e_1 \neq e_2 \neq e_3 \neq e_4 \neq 0$; $H_o \neq f_1 \neq f_2 \neq f_3 \neq f_4 \neq 0$; $H_o \neq g_1 \neq g_2 \neq g_3 \neq g_4 \neq 0$. Commonly, the ARDL bound testing approach is used to explore long-run cointegration among the specified variables of a model. The upper and lower bounds of the critical value are compared to the calculated F-statistic value. The null hypothesis of no cointegration is rejected when the upper limit of the critical value is less than the evaluated F-statistic value, and vice versa. When the measured F-statistic value falls between the top and lower bounds of critical values, however, inaccuracies arise in the results. Once long-run linkage is proven by the bound test, long-run variables may be evaluated using the following Equations (10)–(12):

$$\begin{aligned} new_t = e_0 + \textstyle\sum_{j=1}^{n} e_{4t-1j} new_{t-j} + \sum_{j=1}^{n} e_{t-2j} cto_{t-j} + \sum_{j=1}^{n} e_{t-3j} gro_{t-j} + \\ \textstyle\sum_{j=1}^{n} e_{t-4j} urb_{t-j} + \sum_{j=1}^{n} e_{t-5j} fdi_{t-j} + \mu_{4t}, \end{aligned} \tag{10}$$

$$\begin{aligned} eni_t = f_0 + \textstyle\sum_{j=1}^{n} f_{5t-1j} eni_{t-j} + \sum_{j=1}^{n} f_{t-2j} cto_{t-j} + \sum_{j=1}^{n} f_{t-3j} gro_{t-4j} + \\ \textstyle\sum_{j=1}^{n} f_{t-4j} urb_{t-j} + \sum_{j=1}^{n} f_{t-5j} fdi_{t-j} + \mu_{5t}, \end{aligned} \tag{11}$$

$$\begin{aligned} cde_t = g_0 + \textstyle\sum_{j=1}^{n} g_{t-j} cde_{t-i} + \sum_{j=1}^{n} g_{t-j} cto_{t-j} + \sum_{j=1}^{n} f_{t-3j} gro_{t-4j} + \\ \textstyle\sum_{j=1}^{n} f_{t-4j} urb_{t-j} + \sum_{j=1}^{n} f_{t-5j} fdi_{t-j} + \mu_{6t}, \end{aligned} \tag{12}$$

Equations (13)–(15), which are based on an error correction model, may be used to evaluate short-run parameters when long-run parameters have previously been evaluated using Equations (10)–(12).

$$\begin{aligned} \Delta new_t = e_0 + \textstyle\sum_{j=1}^{n} e_{4t-1j} \Delta new_{t-j} + \sum_{j=1}^{n} e_{t-2j} \Delta cto_{t-j} + \sum_{j=1}^{n} e_{t-3j} \Delta gro_{t-j} + \\ \textstyle\sum_{j=1}^{n} e_{t-4j} \Delta urb_{t-j} + \sum_{j=1}^{n} e_{t-5j} \Delta fdi_{t-j} + e_{t-6j} \lambda_{t-1} + \mu_{4t}, \end{aligned} \tag{13}$$

$$\begin{aligned} \Delta eni_t = f_0 + \textstyle\sum_{j=1}^{n} f_{5t-1j} \Delta eni_{t-j} + \sum_{j=1}^{n} f_{t-2j} \Delta cto_{t-j} + \sum_{j=1}^{n} f_{t-3j} \Delta gro_{t-4j} + \\ \textstyle\sum_{j=1}^{n} f_{t-4j} \Delta urb_{t-j} + \sum_{j=1}^{n} f_{t-5j} \Delta fdi_{t-j} + f_{t-6j} \lambda_{t-1} + \mu_{5t}, \end{aligned} \tag{14}$$

$$\begin{aligned} \Delta cde_t = g_0 + \textstyle\sum_{j=1}^{n} g_{t-j} \Delta cde_{t-i} + \sum_{j=1}^{n} g_{t-j} \Delta cto_{t-j} + \sum_{j=1}^{n} f_{t-3j} \Delta gro_{t-4j} + \\ \textstyle\sum_{j=1}^{n} f_{t-4j} \Delta urb_{t-j} + \sum_{j=1}^{n} f_{t-5j} \Delta fdi_{t-j} + g_{t-6j} \lambda_{t-1} + \mu_{6t}, \end{aligned} \tag{15}$$

In Equations (13)–(15), λ denotes the error correction term. This demonstrates the equilibrium adjustment speed in the long-run following short-run shock, assuming a substantial and between 0 and -1 value of λ. In addition, the statistical significance of this coefficient provides more evidence that the long-run relationship is present. Moreover, for the purpose of determining whether or not the model is accurate, this study carried out the normality test, the serial correlation test, and the heteroscedasticity test. Additionally, the cumulative sum and the cumulative sum of squares were calculated.

4. Results and Discussion

4.1. Unit Root Test

For time series analysis, to guarantee that regression can be performed, it is essential to verify prior to performing the regression if the series being investigated is stable or, in other words, if it contains unit roots. The Augmented Dickey–Fuller unit root test is used in this article. The results are shown in Table 2.

Due to the fact that the null hypothesis, which shows that there is a unit root, is not rejected, the findings of the investigation presented in this article indicate that the variables under consideration are not stationary at their own levels. The null hypothesis is rejected, however, when the variables are taken into account as the first-order difference. This indicates that the variables that were used in this study are stationary at their respective first-order differences. As a consequence of the fact that the precondition that the preceding analysis posed for the cointegration analysis has been satisfied, the cointegration test is carried out in the next subsection.

Table 2. Results of unit root test.

Variable	Level	First Difference	Result
cde	−1.426	−3.559 *	I(1)
new	0.705	−4.835 ***	I(1)
eni	−1.408	−0.010 **	I(1)
cto	−2.105	−4.172 **	I(1)
gro	1.443	−4.636 ***	I(1)
urb	−0.650	−6.010 ***	I(1)
fdi	2.329	−4.472 ***	I(1)

Note: * 10% significant level; ** 5% significant level; *** 1% significant level.

4.2. Cointegration Test

Following Pesaran et al. [64], the boundary test approach is being used in this investigation as a result of its two primary benefits. Specifically, the first benefit is that, while conducting the boundary test, it is not necessary to take into account whether the variables in question are subject to I(0), I(1), or a combination of I(0) and I(1). The second advantage is that the boundary test may be applied even with a limited number of samples while researching time series. In this investigation, the time span from 2000 to 2021 is utilized, and there is only a total of 22 observations, which results in a rather limited sample. The reasons for this are explained above. As a result, the approach of the boundary test is implemented to assess whether or not there is a link between variables over the long run. According to Pesaran et al. [64], the asymptotic distribution of the F statistic value is deemed to be non-standard, which means that I(0) or I(1) may not be taken into account. A positive result can be obtained regardless of whether the variables are I(0) or I(1) or whether the F statistic value that was computed falls below the crucial value range. When the F statistic value exceeds the upper critical value, a long-term equilibrium connection exists between the variables under consideration. On the contrary, when the F statistic value falls below the lower critical value, a long-term equilibrium connection does not exist between the variables under consideration. If the value of the F statistic is found to be between the upper and lower critical values, it is not possible to determine whether or not the variables have a long-term association with one another. The findings of the cointegration test are then shown in Table 3.

Table 3. Results of cointegration test.

Equation	F-Statistic Value	Significant Level	I(0)	I(1)
cde = f(cti, gro, urb, fdi)	7.058 ***	1%	3.29	4.37
		5%	2.56	3.49
		10%	2.20	3.09
new = f(cti, gro, urb, fdi)	22.375 ***	1%	4.09	5.53
		5%	2.95	4.08
		10%	2.46	5.532
eni = f(cti, gro, urb, fdi)	6.562 ***	1%	4.28	5.84
		5%	3.06	4.22
		10%	2.52	3.56

Note: *** 1% significant level.

The findings shown in Table 3 reveal that the calculated F-statistic value for the carbon dioxide emissions equation is 7.058, which is higher than the upper critical value of 4.37. In other words, there is a long-run relationship between communication technology trade openness and carbon dioxide emissions. The calculated F-statistic value for the renewable energy consumption equation is 22.375, which is higher than the upper critical value of 5.53. In other words, there is a long-run relationship between communication technology trade openness and renewable energy consumption. The calculated F-statistic value for the energy intensity equation is 6.562, which is higher than the upper critical value of 5.84.

In other words, there is a long-run relationship between communication technology trade openness and energy intensity.

4.3. Effect of CTO on Energy Transformation and Environmental Quality

The purpose of this article is to investigate the effects of CTO on energy transformation and environmental quality in the short and long runs. The results of the short-run effect are shown in Table 4.

Table 4. Results of the short-run effects.

Carbon Dioxide Emissions		Renewable Energy		Energy Intensity	
Variable	**Coefficient**	**Variable**	**Coefficient**	**Variable**	**Coefficient**
Δcde_{-1}	0.395 *** (6.349)	Δnew_{-1}	0.466 *** (11.387)	Δei_{-1}	−0.717 *** (−4.239)
Δcto	−0.231 *** (−6.258)	Δcti	0.099 *** (4.242)	Δcto	−0.634 *** (−4.844)
Δgro	0.028 *** (8.940)	Δgro	0.084 ** (2.346)	Δgro	0.008 * (1.987)
Δurb	0.028 ** (2.614)	Δurb	0.007 * (1.632)	Δgro_{-1}	0.027 *** (4.876)
Δfdi	0.011 * (0.721)	Δfdi	0.012 * (1.801)	Δfdi	0.042 ** (2.665)
		Δfdi_{-1}	0.020 * (1.708)		
ecm_{-1}	−0.069 *** (−6.178)	ecm_{-1}	−0.017 *** (−5.483)	ecm_{-1}	−0.186 *** (−9.161)

Note: * 10% significant level; ** 5% significant level; *** 1% significant level; value of t-statistic shown in the parentheses.

In the equation for carbon dioxide emissions, it is discovered that CTO has a negative effect on carbon dioxide emissions in the short term. More specifically, a 1% rise in CTO results in a decrease of 0.231% in carbon dioxide emissions. The system, which combines CTO and carbon dioxide emissions, is now diverging from the connection that exists in the long-run equilibrium state as a result of shocks that occur in the short run. In the next period, the error correction mechanism will bring the short-run fluctuation to the long-run equilibrium relationship at an adjustment speed of 0.069%. The importation of a large number of foreign technologies with advanced capabilities to replace domestic technologies that were relatively inefficient has led to an increase in the utilization rate of non-renewable energy as well as the promotion of the development of renewable energy, which has resulted in a reduction in carbon dioxide emissions. This is one of the possible reasons for this phenomenon. In addition, this may assist China in reaching carbon neutrality by the year 2060. The findings of Barş-Tüzemen et al. [66], Amri [67], and Jin et al. [68] all provide credence to this conclusion. Meanwhile, economic growth, urbanization, and foreign direct investment positively affect carbon dioxide emissions in the short run.

In the equation for the consumption of renewable energy, it is found that trade openness in information and communication technologies is beneficial to the consumption of renewable energy in the short term. More specifically, a 1% rise in CTO leads to a 0.099% in the use of renewable energy. As a consequence of shocks that take place in the short run, the system, which is comprised of CTO and renewable energy consumption, is currently deviating from the link that exists in the long-term equilibrium state. The error-correcting method will bring the short-run fluctuation to the long-run equilibrium relationship at an adjustment speed of 0.017% during the subsequent period. Productivity may increase if more sophisticated foreign technology is brought in from other countries, as one probable explanation suggests. Meanwhile, cutting-edge technology serves as an essential component of the foundation for the growth of renewable energy sources such as wind power and hydropower. As a result, China's renewable energy sector has the potential to progress with the assistance of cutting-edge technology swiftly. This conclusion is backed up by the research of Rehman et al. [69], Caglar et al. [70], and Shahzad et al. [71]. In the meantime, economic growth, urbanization, and foreign direct investment have a favorable impact on renewable energy consumption in the short run.

In the equation for energy intensity, it is observed that CTO has a negative influence on energy intensity; more specifically, a 1% rise in CTI results in a fall of 0.634% in energy intensity. The system, which is now diverging from the connection that exists in the long-term equilibrium state as a result of shocks that take place in the short run, is currently constituted of CTO and energy intensity. During the ensuing period, the error-correcting mechanism will make an adjustment that will move the short-run fluctuation closer to the long-run equilibrium relationship at a speed of 0.186%. One of the possible reasons for this is that information and communication technology not only helps to eliminate redundancy and waste in the production process, but it can also coordinate with other energy-saving measures that firms implement in order to improve energy utilization efficiency and reduce energy intensity. This conclusion is corroborated by the research carried out by Lu [72], Sharma et al. [73], and Weili et al. [74]. Similarly, economic growth, urbanization, and foreign direct investment all have a positive influence on energy intensity in the short run.

Next, we will investigate how long-term changes in energy transformation and environmental quality are impacted by trade openness in information and communication technology. Table 5 displays the findings with regard to the long-term influence.

Table 5. Results of long-run effects.

Carbon Dioxide Emissions		Renewable Energy		Energy Intensity	
cto	−0.235 ** (−3.263)	cto	0.150 ** (2.059)	cto	−0.499 *** (−5.371)
gro	0.744 *** (2.547)	gro	0.635 *** (3.945)	gro	−0.144 ** (−2.190)
urb	0.218 * (1.735)	urb	0.085 * (1.183)	urb	−0.205 * (−1.790)
fdi	0.337 *** (4.127)	fdi	0.099 *** (4.516)	fdi	0.162 *** (5.004)
c	−0.076 (−0.174)	c	0.531 *** (3.3444)	c	1.232 *** (5.370)

Note: * 10% significant level; ** 5% significant level; *** 1% significant level; value of t-statistic shown in the parentheses; c constant.

According to the findings shown in Table 5, it appears that trade openness in information and communication technology, in the long run, has a negative impact on the amount of carbon dioxide emissions. The findings of Park et al. [75], Nguyen et al. [76], and Al-dakhil et al. [77] all lend credence to this conclusion. In addition, the results give evidence in support of Hypothesis 2 (H2). When looking at the long-term effects of the energy transition, it has been discovered that trade openness in information and communication technology has a favorable impact on the consumption of renewable energy while having a negative effect on energy intensity. The findings are in line with those found in the studies carried out by Lee et al. [78], Haldar and Sethi [79], Irfan et al. [80], and Murshed et al. [81]. Furthermore, the findings provide evidence in favor of Hypothesis 1 (H1).

4.4. Diagnostic Tests

A battery of diagnostic tests was undertaken to ensure the reliability and accuracy of our findings presented in Tables 4 and 5. On the calculated models' residuals, the heteroscedasticity, serial correlation, normal distribution, and functional misspecification tests were performed to evaluate both the residuals and the stability diagnostics of the model. The results are shown in Table 6.

Table 6. Results of diagnostic tests.

Statistical Method	Statistical Value	*p*-Value
	Carbon dioxide emissions	
χ^2_{ARCH}	0.971	0.338
χ^2_{SERIAL}	2.769	0.122
χ^2_{RESET}	0.614	0.453
χ^2_{NORMAL}	0.796	0.671
CUSUM	Stable	
CUSUM of squares	Stable	
	Renewable Energy	
χ^2_{ARCH}	0.308	0.585
χ^2_{SERIAL}	2.187	0.163
χ^2_{RESET}	0.277	0.608
χ^2_{NORMAL}	0.836	0.658
CUSUM	Stable	
CUSUM of squares	Stable	
	Energy Intensity	
χ^2_{ARCH}	0.752	0.397
χ^2_{SERIAL}	0.918	0.250
χ^2_{RESET}	0.033	0.860
χ^2_{NORMAL}	0.223	0.894
CUSUM	Stable	
CUSUM of squares	Stable	

Note: CUSUM cumulative sum of recursive residuals.

According to the results presented in Table 6, there is no evidence of either heteroscedasticity or serial correlation. In spite of the fact that the functional form of the model is accurately recognized and described, there is no evidence to support the hypothesis of a residual normal distribution. In addition, the results of the cumulative sum test as well as the cumulative sum squared test, provide credence to the model's stability.

5. Conclusions

Over time, China's economic growth model that relied on nonrenewable energy and sacrificed the environment became more inappropriate. Therefore, energy transformation and environmental protection are now challenging concerns for China. This article investigates the effects of CTO on China's energy transformation and environmental quality utilizing yearly data from 2000 to 2021 and the autoregressive distributed lag model. According to the results, the openness of trade in information and communication technology has a positive influence on environmental quality. This is due to the fact that it has a negative impact on carbon dioxide emissions. In addition, the results indicate that the openness of trade in information and communication technology has a positive influence on the transformation of energy, owing to the fact that it has a positive impact on the consumption of renewable energy and a negative impact on energy intensity.

As a result, in accordance with the conclusions of this article as a whole, several commendations are presented as follows: (1) it is proposed that the government of China progressively liberalize the trade obstacles that restrict the movement of products and services related to information and communications technology across international borders. (2) It is advocated that effective steps should be taken to minimize the overwhelming usage of non-renewable energy sources and to increase the use of renewable energy sources as a source of economic incentive. (3) It is suggested that because the effects of information and communications technology on carbon dioxide emissions are discovered to be primarily contingent on the form of energy resources that are consumed, openness of the barriers should be constructed diligently so that it supports the trade of the relatively greener information and communication technology commodities that have the capability to implement and manage on energy sourced from sources of renewable energy and are also relatively energy-efficient. This, in turn, could be a reliable means to protect both the energy transformation and the environmental quality. (4) It is proposed that downsizing the policies governing foreign investment should also be taken into consideration for the purpose of attracting foreign direct investments into the information and communication technology segments in China. As a result of the skills spillover effect associated with these foreign investments, this would be beneficial in developing these segments.

Additionally, the literature is advanced in the following three ways as a result of the results of this article: (1) in this study, a particular analysis of the implications of expanding openness of information and communication technology trade is conducted for the purpose of supporting renewable energy technology, accessing energy intensity, and lowering carbon dioxide emissions for the purpose of ensuring energy transformation and environmental quality in China. Even though a large number of previous studies have investigated the effects of utilizing information communication technology goods such as Internet use, mobile services, and fixed broadband subscriptions, the effects of liberalizing trade barriers that affirm the cross-border information communication technology goods and services flows have not yet been documented in the published research. (2) To the best of our knowledge, this is brand-new research that covers the functions of information and communications technology trade, as stated before, in the context of China. (3) The possible long-term and short-term connection between the openness of trade in information and communications technologies and the above-described indices of energy transformation and environmental quality is investigated.

Additionally, this article does have a few limitations, but it does point future researchers to some fresh avenues for their study. (1) To investigate this subject, this research focuses only on the time series. In light of the unequal development that has occurred across China, it is possible that future researchers may employ provincial panel data to investigate this subject again. It is possible that their results will be more fascinating. (2) This study might be expanded as a component of the future investigation's scope by further isolating CTO into commodity-specific trade openness in order to evaluate the possible heterogeneity of the consequences. It is important to accomplish this because, despite the fact that a myriad of previous studies has investigated the effects of information and communication technology goods, particularly mobile and Internet subscriptions, on renewable energy, energy intensity, and carbon dioxide emissions, relatively little has been identified in the frame of reference of the dynamic effects associated with the openness of the barriers that constrain the trade of these essential information and communication technology goods. (3) The general robustness of the results might be improved by including a variety of energy sources and a wide range of metrics of environmental quality in the investigation. (4) This examination of the effects of trade in information and communications technologies on energy transformation and environmental quality may also be undertaken for the unique instances of different regions and countries. (5) This paper's use of carbon dioxide emissions as an indicator of environmental quality may not be completely accurate. Future researchers may use an alternative, more suitable proxy variables to investigate this issue. This may result in a more trustworthy conclusion.

Author Contributions: Conceptualization, Y.H.; methodology, Y.H.; software, Y.W.; validation, Y.W.; formal analysis, Y.H.; investigation, Y.W.; data curation, Y.W.; writing—original draft preparation, Y.W.; writing—review and editing, Y.H.; visualization, Y.W.; supervision, Y.H.; project administration, Y.H.; funding acquisition, Y.W. All authors have read and agreed to the published version of the manuscript.

Funding: This work was supported by BK21 FOUR Program by Jeonbuk National University Research Grant.

Data Availability Statement: The data presented in this study are available from the authors upon request.

Conflicts of Interest: The authors declare no conflict of interest.

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