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Investigating the Routes toward Environmental Sustainability: Fresh Insights from Korea

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Abstract: The environmental issues that have arisen as a result of brisk economic expansion have evolved into a barrier to the process of social development. Based on this background, this article investigates the consequences of economic development, energy consumption, and urbanization on greenhouse gas emissions (a proxy for environmental sustainability) in Korea. Using the data from 1990 to 2019 and employing the autoregressive distributed lag method for empirical investigations, the results demonstrate that economic expansion, urbanization, and non-renewable energy consumption all constitute a danger to environmental sustainability because they positively influence greenhouse gas emissions. Oppositely, the results demonstrate that renewable energy consumption enhances environmental sustainability because it negatively impacts greenhouse gas emissions. Furthermore, a fresh discovery is that these results are consistent over time. In addition, the results of the causality test show that two-way causal links between economic growth, non-renewable energy consumption, and greenhouse gas emissions have been found in both the short and long runs, whereas unidirectional causal links between urbanization, renewable energy consumption, and greenhouse gas emissions have also been discovered. The most significant contribution that the results of this study may make is that they can provide several policy proposals for environmental sustainability in Korea and expand the literature that already exists on this issue in Korea.

Keywords: environmental sustainability; autoregressive distributed lag method; greenhouse gas emissions; non-renewable energy consumption; renewable energy consumption

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1. Introduction

Climate change is a worldwide environmental challenge. The primary driver of this phenomenon is the rise of greenhouse gas concentrations in the atmosphere. The three most significant greenhouse gases are thought to be carbon dioxide, methane, and nitrous oxide. The United Nations has made it abundantly clear that all countries are obligated to protect the interests of the climate system for the welfare of both present and future generations of humankind on the basis of equity, in accordance with their shared responsibilities and their individual capabilities. It is imperative that developed countries take the initiative to spearhead the fight against climate change and the devastation it causes. Korea, like many other developed countries, finds itself in the position of having to deal with the issue of greenhouse gas emissions. According to a report that was published by Yonhap on 28 June 2022, the preliminary statistical data that was released by the Korean Greenhouse Gas Comprehensive Information Center showed that the greenhouse gas emissions of South Korea in the previous year (in terms of carbon dioxide) were 679.6 million tons. This represented an increase of 3.5% over the same period of time in the previous year (656.6 million tons), and it showed that they had rebounded after three years. There was a modest rise to 13.1 tons of emissions produced per person.

After hitting a record high of 727 million tons in 2018, South Korea's greenhouse gas emissions declined for two consecutive years before rebounding for the first time in 2020. According to the research conducted by Rasti-Barzoki and Moon [1] and Jin [2], this is mostly caused by a slow return to the levels of production and population movement before the COVID-19 outbreak. In particular, the energy sector's greenhouse gas emissions increased by 3.6% year-over-year to 590.6 million tons in 2016, accounting for 87% of the overall emissions that year. Power generating and heating accounted for the largest share (37%) of energy sector emissions, which rose 1.8% year-over-year to 222 million tons. Notable is that because coal-fired power generation is decreasing and liquefied natural gas and renewable energy are increasing, power generation increased by 4.5% year-over-year in 2016 while actual emissions decreased from 0.395 tons per megawatt hour in 2020 to 0.385 tons per megawatt hour in 2021. In addition, in South Korea, the acceleration of urbanization and the manner of economic development that is dominated by fossil fuels are both concerns that cannot be overlooked.

This article's aim is to learn more about how Korean environmental sustainability might be achieved by studying the period from 1990 to 2019. Utilizing the empirical research technique known as autoregressive distributed lag approach for an investigation revealed that economic growth, urbanization, and non-renewable energy consumption all constitute a considerable danger to environmental sustainability because they positively impact greenhouse gas emissions. Furthermore, the results suggest that renewable energy consumption contributes to environmental sustainability since it negatively impacts the emission of greenhouse gases. In addition, the results are consistent over time. Meanwhile, using the causality test for further investigation revealed that unidirectional causal links exist between renewable energy consumption, urbanization, and greenhouse gas emissions. Moreover, two-way causal links between economic growth, greenhouse gas emissions, and non-renewable energy consumption have also been found to exist over time.

This study's findings add to the corpus of previously accumulated Korean literature on environmental sustainability. First, the studies completed by Choi and Song [3] and Lee et al. [4], which simply concentrated on the environmental impacts of renewable energy, are built upon by this study, which undertakes an analysis of the environmental effects of renewable energy versus non-renewable energy. This will aid the Korean government in its allocation of energy resources. Second, in Korea, excessive urbanization presents a danger to environmental sustainability. The Korean Bureau of Statistics reports that two-thirds of Korea's population dwells in Seoul, and the city produces tremendous pressure on the environment. The conclusion of this study provides the most recent proof to aid the Korean government in addressing the environmental pressure problem in Seoul and adds information to the literature in Korea. Third, in this body of work, not only the long-run implications of the emphasized variables on environmental sustainability but also the short-term consequences of those variables are investigated. This research contributes new information to the existing body of literature in Korea, particularly when compared to the investigations conducted by Waheed et al. [5], Chang et al. [6], and Park and Yun [7].

The remaining portions of this document are structured as follows: in Section 2, a review of available literature is offered; in Section 3, we take a look at the variables and the model; Section 4 contains both the findings and an explanation of this work; the conclusion is provided in Section 5.

2. Literature Review

This section's purpose is to undertake a literature review on the topic of this article, with the findings serving as the article's theoretical foundation. This section is broken down into four subsections for in-depth examination. The first subsection is to analyze how non-renewable energy consumption influences greenhouse gas emissions. The second subsection is to study how renewable energy consumption influences greenhouse gas emissions. The third subsection is to examine how urbanization influences greenhouse gas emissions. The fourth subsection is to analyze how economic growth influences greenhouse gas emissions.

Non-renewable energy is a type of energy that has been generated in nature for hundreds of millions of years and cannot be recovered in a short period of time It is energy that is developed and used on a massive scale. Specifically, non-renewable energy sources are crude oil, coal, natural gas, nuclear energy, oil shale, and other sources. Consumption of these fossil fuels is a major consideration that, as is well known, cannot be discounted in terms of its contribution to the emissions of greenhouse gas. Throughout the course of the following investigations, data from 1970 to 2016 and a technique known as variance decomposition were used. Zaidi et al. [8] found that Pakistan's reliance on natural gas and coal was the primary factor contributing to the country's inability to adequately maintain environmental sustainability. Zhang et al. [9] determined that fossil fuel consumption was, in fact, the primary contributor to the increase in emissions of carbon dioxide over the period of 1970–2012. Using a cointegration and causality framework, Boontome et al. [10] examined the causal linkage between Thailand's non-renewable energy consumption and carbon dioxide emissions from 1971 to 2013. They discovered a unidirectional causal link between carbon dioxide emissions and non-renewable energy consumption. This implied that non-renewable energy consumption might undermine environmental sustainability. Additionally, in the case of South Korea, Zhang et al. [11] used the meta-frontier non-radial directional distance function to investigate the effect of fossil fuel energies on carbon dioxide emissions. They discovered that fossil fuel energies contributed to carbon dioxide emissions significantly. Furthermore, Oh and Yoo [12], Oh et al. [13], Shin et al. [14], and Jin et al. [15] also supported this finding. Sahoo and Sahoo [16] employed the Toda-Yamamoto Granger model in their investigation of this topic, which included data spanning from 1965 to 2018 and a representative sample from India. They too discovered that the use of energy sources that do not regenerate led to the release of carbon dioxide. However, their finding was not statistically significant. In addition, the conclusions of Nakhli et al. [17], Adebayo and Rjoub [18], Amin et al. [19], Imran et al. [20], and He and Zhang [21], all lent their credence to these conclusions. Thus, Hypothesis 1 (H1) is proposed in this research according to the analysis of the aforementioned body of literature:

Hypothesis 1 (H1). *Environmental sustainability is adversely impacted by the use of non-renewable energy.*

Renewable energy is an essential component of the energy supply system, which is important for enhancement of the energy structure, preservation of the ecological environment, management of climate change, and accomplishment of sustainable economic and social growth. Jin et al. [22] studied the cointegration and causal link between carbon dioxide emissions and renewable energy consumption using panel data from 2000 to 2017. In all of the economies that they reviewed, they discovered a two-way causal link existing between carbon dioxide emissions and renewable energy, despite the fact that there were considerable disparities. Using data from 1980 to 2011 and the STIRPAT model, Shafiei and Salim [23] investigated the factors that determined carbon dioxide emissions for OECD countries. They discovered that a decrease in carbon dioxide emissions was brought about through the use of renewable energy sources. Moreover, Waheed et al. [24] looked into this topic in Pakistan. They used annual data over the period of 1990–2014 and the autoregressive distributed lag model to look at the long-term and short-term effects of renewable energy on carbon dioxide emissions. They observed that using renewable energy had a negative impact on carbon dioxide emissions both in the long run and in the short run. Moreover, using South Korea as the case, Jun et al. [25] employed the long-range energy alternative planning model to revisit the same topic. They found that renewable energies such as landfill gas, wind, and solar energy reduced carbon dioxide emissions. In spite of the fact that Cho and Kim [26], Koc and Bulus [27], Adebayo et al. [28], and Nam et al. [29] utilized distinct approaches, they all arrived at the same result using South Korea as their example. In addition, these findings were supported by research from Jebli et al. [30], Dogan and Seker [31], Razmjoo et al. [32], and Imran et al. [33]. Consequently, Hypothesis 2 (H2) is suggested in this article according to investigation of the aforementioned body of literature:

Hypothesis 2 (H2). *Environmental sustainability is favorably influenced by the use of renewable energy sources.*

According to related theories and previous investigations, it is acknowledged that the process of urbanization may have both positive and negative effects on environmental sustainability and that it is difficult to predict a priori what the net effect will be. Sadorsky [34] made use of newly established panel regression methods in order to estimate the impact of urbanization on carbon dioxide emissions in terms of a group of rising economies. He determined that urbanization had a favorable influence on carbon dioxide emissions. Wang et al. [35] conducted an empirical investigation of the connection between carbon dioxide emissions and urbanization, paying particular attention to the varying levels of national income present in the countries that were analyzed. Using a number of panel data models, they found that urbanization had a long-run beneficial influence on carbon dioxide emissions for 170 nations during the period 1980–2011. However, Martínez-Zarzoso and Maruotti [36] studied urbanization's impact on developing nations' carbon dioxide emissions between 1975 and 2003. Using the STIRPAT model for empirical study, they discovered a U-shaped link between carbon dioxide emissions and urbanization. Using the sample approach, Zhang and Lin [37] found that carbon dioxide emissions were only positively affected by urbanization during the period 1995–2010 in China. Meanwhile, the results shown above have been corroborated by Poumanyvong and Kaneko [38], AI-Mulali et al. [39], and Zhu et al. [40]. Consequently, Hypothesis 3 (H3) is proposed in this investigation, which is based on an examination of the aforementioned corpus of published research:

Hypothesis 3 (H3). *Environmental sustainability is favorably impacted by urbanization.*

Recent years have seen a period of tremendous economic development, which has been one of the elements that has contributed to environmental deterioration. A large number of academics have similarly carried out in-depth research on this topic. Acheampong [41] examined the dynamic causal link between carbon dioxide emissions and economic growth for 116 countries during the period 1990–2014 using both PVAR and S-GMM for empirical investigation. They determined that economic growth did not have any causal influence on carbon dioxide emissions anywhere. However, they found that economic growth negatively influenced carbon dioxide emissions in terms of the global level and the Caribbean-Latin American levels. Meanwhile, utilizing the Toda-Yamamoto approach, Lotfalipour et al. [42] explored the causal links between carbon dioxide emissions and economic growth with a sample of Iran during the period 1967–2007. They discovered that a driver for carbon emissions was the expansion of the economy. Mardani et al. [43] also supported this finding. In addition, their findings were supported by research from Heidari et al. [44], Saidi and Hammami [45], and Ozturk and Acaravci [46]. Consequently, Hypothesis 4 (H4) is suggested in this investigation, which is based on an evaluation of the corpus of published research described previously:

Hypothesis 4 (H4). *Environmental sustainability is favorably impacted by economic growth.*

3. Variables and Model

3.1. Variables

This article's aim is to explore a pathway to environmental sustainability with a case study of Korea from 1990 to 2019. It has been discovered via investigation into the relevant literature that there are several proxies for environmental sustainability. According to the studies of Saint Akadiri et al. [47] and Kirikkaleli and Adebayo [48], emissions of greenhouse gases are treated as a factor negatively influencing Korean environmental sustainability. In the meantime, this article incorporates economic growth, renewable energy consumption, urbanization, and non-renewable energy consumption as a response to Xue et al. [49], Ulucak and Ozcan [50], Miao et al. [51], Akadiri and Adebayo [52], and Li et al. [53]. Table 1 provides specifics on these variables.

Table 1. Variable description.

Variable	Form	Definition
Greenhouse gas emissions	gg	Gross greenhouse gas emissions (unit: million metric tons) in log
Non-renewable energy consumption	ne	Fossil fuel energy consumption (% of total)
Renewable energy consumption	re	Renewable energy consumption (% of total final energy consumption)
Urbanization	ur	Ratio of urban population to gross population
Economic growth	eg	GDP (constant 2015 USD; unit: billion USD) in log

Note: all data used in this article were collected from World Development Indicators.

3.2. Sample Selection

South Korea's greenhouse gas emissions are high owing to thermal power production, automotive exhaust emissions, industrial pollution, and other factors. In addition to recognizing that limiting carbon emissions is an essential national priority, the Korean government has adopted a number of relevant actions, such as issuing stricter environmental regulations and encouraging technological innovation. The National Assembly enacted related legislation in September 2021, making South Korea the fourteenth nation in the world to implement a carbon neutral law. The measure stipulates that greenhouse gas emissions be reduced by at least 35% below 2018 levels by 2030. The government resolved in October 2021 to increase the national independent contribution reduction goal for greenhouse gas emissions in 2030 from 26.3% to 40% and to attain "carbon neutrality" by 2050. South Korea became the first East Asian nation to proclaim, "net zero carbon emissions". To reduce carbon emissions, coal-fired electricity production will cease entirely by 2050. To sum up, the information presented above is the primary context or motivation for the choice of South Korea as the sample to investigate this topic in this article.

3.3. Model

In the present investigation, the frameworks of Shahbaz et al. [54], Behera and Dash [55], and Zhang et al. [56] are used to analyze the consequences of economic development, energy consumption, and urbanization on environmental sustainability. The framework is described as follows:

$$gg_t = f(nc,\ rc,\ eg,\ ur) \tag{1}$$

where $f(\cdot)$ stands for a kind of function. According to Özokcu and Özdemir [57] and He et al. [58], converting linear model into log form is a straightforward method for achieving stationarity in the variance–covariance matrix. As a direct consequence of this, Equation (1) is rephrased as follows:

$$gg_t = \alpha_0 + \alpha_1 nc_t + \alpha_2 rc_t + \alpha_3 eg_t + \alpha_4 ur_t + \mu_t \tag{2}$$

where t stands for year; α_0 stands for constant; $[\alpha_1, \alpha_4]$ stand for coefficients required to be estimated; μ_t stands for white noise. Referring to the literature [59,60], the long-term relationships between the various variables were investigated by using the autoregressive distributed lag bound test. The benefit of using this method is that it does not involve validating the variables' unit roots, which is a disadvantage of other approaches, even if some series include integration at the level. On the contrary, this approach cannot be used for any variable with I(2). Therefore, the unit root test is employed to validate the highlighted variables' stationarity in this article. A variable is considered non-stationary when the probability distribution of a variable's mean variance and co-variance varies with time. The ADF (augmented Dickey–Fuller) test, which was designed by Dickey and Fuller [61], and the PP test, which was designed by Phillips and Perron [62], are the two unit root tests that are most often employed in the research that has been published. In this investigation, an ADF test was used to determine whether or not the unit root exists. The structural break in the variables, which was stressed by Perron [63], had to be taken into consideration while looking at the unit root. Baum [64] found that using the ADF and PP tests could result in incorrect conclusions if there was a structural break in the variable. As a result, the unit root test which was designed by Zivot and Andrews [65] is employed in this paper to overcome this shortcoming.

After determining whether or not the variables were stationary, the method of cointegration that is based on the autoregressive distributed lag bound test, which has seen the most widespread application, was used in this article. It is possible to investigate both short-run and long-run impacts simultaneously by employing the autoregressive distributed lag method, which is a valuable approach. Similarly, Otero and Smith [66] and Zhou [67] emphasized that the utility and applicability of this method extends to both the features of small and large samples. In addition, Pesaran and Shin [68] discovered that this approach enabled the model to be implemented despite the randomness of the information for the independent variable. When using the autoregressive distributed lag approach, it is not necessary for the studied variables to have the same order of cointegration. The model is rephrased as follows:

$$\Delta gg_t = \beta_0 + \beta_1 gg_{t-1} + \beta_2 nc_{t-1} + \beta_3 rc_{t-1} + \beta_4 eg_{t-1} + \beta_5 ur_{t-1} + \sum_a^q \gamma_a \Delta gg_{t-a} + \sum_b^q \gamma_b \Delta nc_{t-b} + \sum_c^q \gamma_c \Delta rc_{t-c} + \sum_d^q \gamma_d \Delta eg_{t-d} + \sum_e^q \gamma_e \Delta ur_{t-e} + \mu_t \quad (3)$$

where β_0 stands for constant; [β_1, γ_e] stand for the coefficients required to be estimated. Common practice is to determine whether or not cointegration is the underlying hypothesis being tested via the Wald test, which is dependent on F-statistics. This test is performed on the basis of Equation (3), and the results are interpreted accordingly. In most cases, the approach of autoregressive distributed lag bound is employed to detect the cointegration between the considered variables. Both the upper critical value and the lower critical value are computed according to the determined value of F-statistic. When the upper critical value falls below the evaluated value of F-statistic, the null hypothesis ($\beta_1 = \beta_2 = \beta_3 = \beta_4 = \beta_5 = 0$) is rejected. When the evaluated value of the F-statistic locates between the lower critical value and the upper critical value, this shows that the findings are not what they seem to be. Long-run links between the considered variables may be evaluated after the bound test has been applied and the long-run connection has been established. Equation (2) is used for this purpose. It is possible to use Equation (4) with an error correction term, to evaluate short-run parameters when the long-run parameters have previously been evaluated using Equation (2).

$$\Delta gg_t = \delta_0 + \sum_a^q \delta_a \Delta gg_{t-a} + \sum_b^q \delta_b \Delta nc_{t-b} + \sum_c^q \delta_c \Delta rc_{t-c} + \sum_d^q \delta_d \Delta eg_{t-d} + \sum_e^q \delta_e \Delta ur_{t-e} + \lambda ecm_{t-1} + \mu_t \quad (4)$$

where δ_0 stands for constant; [δ_a, λ] stand for the coefficients required to be estimated; ecm_{t-1} stands for the error correction term. The value of λ demonstrates the speed with which an equilibrium will respond in the long run following a shock to the system in the short run. Furthermore, if the value of λ is negative and significant in statistics, the long-run connection can be confirmed.

After confirming the influences of considered variables on environmental sustainability, the Granger causality test is employed for the purpose of determining whether or not the variables that are the subject of the study are connected in a causal manner. In the event that there was a long-run link between the considered variables, Engle and Granger [69] argued that ecm_{t-1} should be taken into consideration in the analysis of the causal relationship. Within a vector error correction model, the causality test is rephrased as follows:

$$\begin{bmatrix} \Delta gg_t \\ \Delta nc_t \\ \Delta rc_t \\ \Delta eg_t \\ \Delta ur_t \end{bmatrix} = \begin{bmatrix} c_1 \\ c_2 \\ c_3 \\ c_4 \\ c_5 \end{bmatrix} + \begin{bmatrix} \zeta_{11,1}, & \zeta_{12,1}, & \zeta_{13,1}, & \zeta_{14,1}, & \zeta_{15,1} \\ \zeta_{21,1}, & \zeta_{22,1}, & \zeta_{23,1}, & \zeta_{24,1}, & \zeta_{25,1} \\ \zeta_{31,1}, & \zeta_{32,1}, & \zeta_{33,1}, & \zeta_{34,1}, & \zeta_{35,1} \\ \zeta_{41,1}, & \zeta_{42,1}, & \zeta_{43,1}, & \zeta_{44,1}, & \zeta_{45,1} \\ \zeta_{51,1}, & \zeta_{52,1}, & \zeta_{53,1}, & \zeta_{54,1}, & \zeta_{55,1} \end{bmatrix} \begin{bmatrix} \Delta gg_{t-1} \\ \Delta nc_{t-1} \\ \Delta rc_{t-1} \\ \Delta eg_{t-1} \\ \Delta ur_{t-1} \end{bmatrix} + \ldots + \begin{bmatrix} \zeta_{11,p}, & \zeta_{12,p}, & \zeta_{13,p}, & \zeta_{14,p}, & \zeta_{15,p} \\ \zeta_{21,p}, & \zeta_{22,p}, & \zeta_{23,p}, & \zeta_{24,p}, & \zeta_{25,p} \\ \zeta_{31,p}, & \zeta_{32,p}, & \zeta_{33,p}, & \zeta_{34,p}, & \zeta_{35,p} \\ \zeta_{41,p}, & \zeta_{42,p}, & \zeta_{43,p}, & \zeta_{44,p}, & \zeta_{45,p} \\ \zeta_{51,p}, & \zeta_{52,p}, & \zeta_{53,p}, & \zeta_{54,p}, & \zeta_{55,p} \end{bmatrix} \begin{bmatrix} \Delta gg_{t-p} \\ \Delta nc_{t-p} \\ \Delta rc_{t-p} \\ \Delta eg_{t-p} \\ \Delta ur_{t-p} \end{bmatrix} + \begin{bmatrix} \lambda_1 \\ \lambda_2 \\ \lambda_3 \\ \lambda_4 \\ \lambda_5 \end{bmatrix} [ect_{t-1}] + \begin{bmatrix} \mu_{1t} \\ \mu_{2t} \\ \mu_{3t} \\ \mu_{4t} \\ \mu_{5t} \end{bmatrix} \quad (5)$$

The significance of $[\lambda_1, \lambda_5]$ in statistics suggests long-run causality. Meanwhile, the joint significance of the first order difference independent parameters in statistics suggests short-run causality via the value of χ^2.

4. Results and Discussion

4.1. Basic Analysis

This subsection's objective is to carry out fundamental analysis, which serves as a prerequisite for the empirical investigation that is to come later. The ADF test, the PP test, and the Zivot–Andrews test are employed to assess the stationarity of the variables in this article. These tests are based on Section 3. Table 2 displays the results.

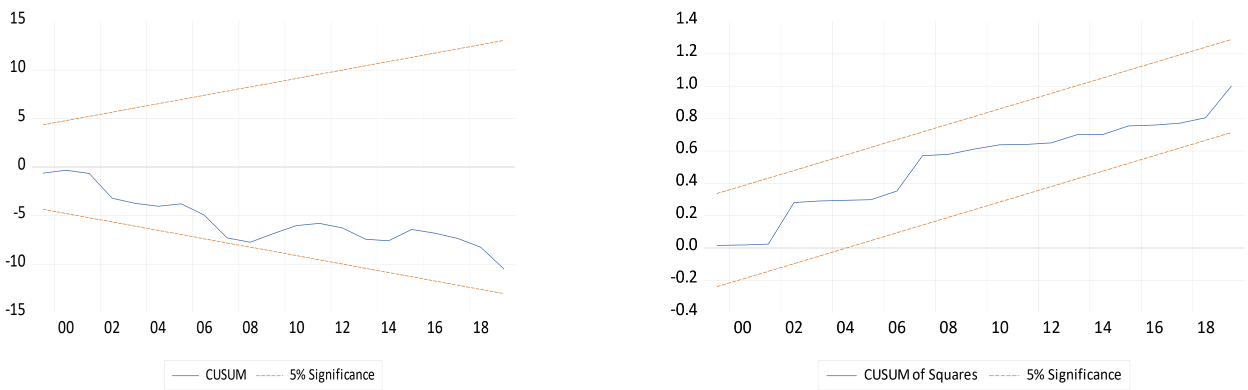
Panel A of Table 2 presents the unit root tests' results. Using the ADF test for estimation, it is discovered that, with the exception of the use of renewable energy, which demonstrates stationarity at its level, the rest of the variables show stationarity after performing the first order difference. When the PP test is used to estimate, it is seen that renewable energy consumption, greenhouse gas emissions, and urbanization are stationary at their levels, while consumption of economic growth and non-renewable energy are stationary at their first difference levels. These tests must be performed prior to applying the autoregressive distributed lag approach. The reason is that the autoregressive distributed lag approach is effective unless all the variables investigated in this paper are stationary at I(0) or I(1). In accordance with Engle and Granger [69], the present measured ADF results support the implementation of the autoregressive distributed lag approach. In particular, with respect to the ADF test and PP test, the Zivot–Andrews test is used to examine the variables' stationarity and to solve the issue of the variables' structure break, both of which are issues that are not taken into account by the ADF test and PP test. In Panel B, the results of the Zivot–Andrews test suggest that, at level, urbanization and economic growth demonstrate stationarity, whereas the other variables demonstrate non-stationarity. However, these variables exhibit stationarity at their first difference levels. The obtained findings validate the mixed-order integration of the variables, satisfying the necessary requirement for employing the autoregressive distributed lag technique to identify short-run and long-run effects.

The usage of the autoregressive distributed lag bound test, which is determined using the F-statistic, is employed to compute the long-run link, and the results of this investigation are shown in Panel C. It was discovered that the estimated value of the F-statistic was higher than the upper critical value when using a significance level of 1%. This indicates that the variables are significantly cointegrated and support a long-run link. Therefore, the null hypothesis is rejected since the present results corroborate the cointegration between the highlighted variables in this study. The model's optimal lag-length, according to the Akaike Information Criterion, is 1, 2, 0, 0, 0. Furthermore, throughout the ongoing study, diagnostic procedures were used in order to confirm the model's robustness. In this respect, there are a variety of tests, such as the results of Panel D, which reflect the findings of several diagnostic tests that have been performed. The findings of these three different types of diagnostic tests give rise to the conclusion that these null hypotheses (no autocorrelation, no heteroscedasticity, and no normality) cannot be rejected. This indicates that the emphasized model in this work is the most appropriate one. Moreover, both CUSUMSQ and CUSUM are used to confirm the model's stability and fitness. As seen by the results of Figure 1, the model's stability is further supported by the findings of CUSUM and CUSUMSQ. The reason is that they all fall in the center of the upper bound and lower bound at 5% significant level.

Table 2. Results of basic analysis.

Panel A: Unit Root Test					
Variable †	ADF Test		PP Test		Conclusion
	Level	1st	Level	1st	
gg	−2.846	−4.844 ***	−4.899 ***	−8.519 ***	I(0); I(1)
ne	−1.411	−4.411 ***	−1.769	−4.402 ***	I(1)
re	−4.418 ***	−4.975 ***	−4.813 ***	−6.108 ***	I(0); I(1)
ur	−2.426	−5.956 ***	−3.458 *	−4.063 **	I(0); I(1)
eg	0.638	−4.596 ***	−2.162	−5.019 ***	I(1)
Panel B: Zivot–Andrews Test					
Variable	Level	B-P	1st	B-P	Conclusion
gg	−3.408	1999	−7.124 ***	1998	I(1)
ne	−3.391	1997	−5.101 ***	1998	I(1)
re	−2.766	2011	−6.119 ***	1996	I(1)
ur	−4.396 *	1995	−9.305 ***	1993	I(0); I(1)
eg	−7.311 ***	1998	−8.219 ***	2002	I(0); I(1)
Panel C: Cointegration Test					
Model	Lag	F-value	Lower and upper critical value		
			Significance	Lower	Upper
gg = f(nc, rc, ur, eg)	(1, 2, 0, 0, 0)	5.176	10%	2.20	3.09
			5%	2.56	3.49
			1%	3.29	4.37
Panel D: Diagnostic Test					
Test	P-value		Conclusion		
B-P-G	0.932		No autocorrelation		
B-G	0.858		No heteroscedasticity		
J-B	0.625		No normality		

Note: *** significance at 1% level; ** significance at 5% level; * significance at 10% level; B-P break point. † Variable abbreviations: gg, greenhouse gas emissions; ne, non-renewable energy consumption; re, renewable energy consumption; ur, urbanization; eg, economic growth.



(**a**) (**b**)

Figure 1. Results of stability test. (**a**) CUSUM test; (**b**) CUSUMSQ test.

4.2. Effects of Highlighted Variables on Environmental Sustainability

This subsection's aim is to examine the impact of the considered variables on environmental sustainability from both a short-run and a long-run point of view. Table 3 displays the results.

Table 3. Results of effects of considered variables on environmental sustainability.

Variable †	Long-Run Effects	Variable	Short-Run Effects
ne	1.555 *** (5.254)	Δne	1.209 *** (2.901)
		Δne_{-1}	0.080 * (1.907)
re	−0.013 *** (−2.907)	Δre	−0.016 *** (−3.223)
ur	0.340 *** (2.747)	Δur	0.415 *** (3.351)
eg	1.077 *** (4.475)	Δeg	1.061 *** (5.255)
		ecm_{-1}	−0.028 *** (−3.393)
trend	−0.009 ** (−2.107)	trend	−0.001 (−0.229)
c	−3.981 * (−1.829)	c	−0.771 (−0.599)

Note: * 10% significant level; ** 5% significant level; *** 1% significant level; value of t-statistic shown in the parentheses. † Variable abbreviations: gg, greenhouse gas emissions; ne, non-renewable energy consumption; re, renewable energy consumption; ur, urbanization; eg, economic growth; c, constant.

The topics of this article that are discussed in relation to the outcomes shown in Table 3 are broken down into two distinct categories. Both long-term and short-term results are going to be discussed in this subsection. Taking the long-run effects into consideration, it is evident that non-renewable energy consumption has a favorable influence on emissions of greenhouse gas. When there is a 1% rise in the use of non-renewable energy, there is a 1.555% rise in the emissions of greenhouse gases. This suggests that the use of non-renewable energy degrades environmental sustainability. The fact that Korea's heavy industry is quite developed and still holds a vital role in Korean economy is one of the probable reasons why this is the case. Because of this, maintaining Korea's industrial system requires a significant quantity of fossil fuel consumption, which in turn results in a significant number of emissions of greenhouse gases and reduces the environmental sustainability of Korea. Moreover, Tsangas et al. [70], Destek and Aslan [71], Djellouli et al. [72], and Karytsas et al. [73] provide evidence that supports this result. This discovery, in the meanwhile, demonstrates that Hypothesis 1 is correct. The coefficient for the consumption of renewable energy has been shown to be significantly negative. When the use of renewable energy sources increases by 1%, greenhouse gas emissions decrease by 0.013%. This indicates that renewable energy consumption is advantageous for environmental sustainability. It is possible that this is due to the fact that the government of Korea has implemented a number of measures that have resulted in the construction of a large number of wind power and tidal power stations in an effort to slow or stop the degradation of the environment. This discovery, on the other hand, is consistent with what Amponsah et al. [74], Lyeonov et al. [75], and Ragazou et al. [76] have discovered. In the meantime, this discovery lends support to Hypothesis 2. Urbanization has a beneficial impact on greenhouse gas emissions. A rise of 1% in urbanization brings about a rise of 0.344% in emissions of greenhouse gases. This indicates that urbanization is not conducive to environmental sustainability. One probable explanation is that the expansion of urbanization in Korea may devastate the country's natural ecosystem. Therefore, maintaining environmental sustainability is challenging. In addition, the findings of Luo et al. [77] and Liobikien and Butkus [78] are in agreement with this finding. At the same time, this discovery lends support to the proposition stated in Hypothesis 3. The expansion of Korean economy has a favorable influence on emissions of greenhouse gases. A rise of 1% in economic growth results in a rise of 1.077% in emissions of greenhouse gases. This suggests that increasing the size of the economy is not beneficial to maintaining a healthy environment. One of the likely reasons for this is that rapid economic expansion is often accompanied by a significant rise in the use of fossil fuels. Meanwhile, Hsiao [79] provides his support for this discovery. Moreover, the notion presented in Hypothesis 4 receives further backing thanks to this finding.

We next turn to the examination of the effects that are seen in the short term. In the study of statistics, the negative value of ecm−1 was discovered. Moreover, it is significant in statistics. This lends support to the impacts in the long term. To be more specific, it indicates that in the next year, any short-run deviation of 0.028% from the long-term equilibrium is readjusted. Similarly, the estimated significant coefficients reveal that a 1% increase in non-renewable energy consumption, urbanization, and economic growth trigger a rise of 1.209%, 0.415%, and 1.061% in greenhouse gas emissions in the short run, respectively, while these results are similar to those conclusions that Mignamissi and Djeufack [80], Fatima et al. [81], and Sun et al. [82] have drawn. Environmental sustainability is broken as a result of the short-run effects of all three of these variables. Nevertheless, the short-run coefficient of consumption of renewable energy is negative. Meanwhile, it is significant in statistics. This suggests that renewable energy consumption helps the maintenance of environmental sustainability. Similarly, this finding is verified by Paris et al. [83] and Kartal [84].

4.3. Robustness Test

It is probable that some key factors impacting greenhouse gas emissions were not considered in this study, which might lead to endogenous problems and bias the estimate findings presented in this study. To guarantee the accuracy and dependability of the findings, we subjected the results of this study to a robustness test. The Markovian switching regression method is utilized as recommended by He and Zhang [21] to reexamine the influence of the variables that were taken into consideration on environmental sustainability. The results are shown in Table 4.

Table 4. Results of robustness test.

Variable †	Regime 1	Regime 2
ne	0.188 *** (5.992)	0.064 *** (6.097)
re	−0.034 *** (−4.442)	−0.018 * (−1.683)
ur	0.239 ** (2.081)	0.124 ** (2.009)
eg	0.112 *** (4.124)	0.103 *** (4.813)
c	−4.446 (−1.336)	−4.993 (−1.125)

Note: * 10% significant level; ** 5% significant level; *** 1% significant level; value of t-statistic shown in the parentheses. † Variable abbreviations: gg, greenhouse gas emissions; ne, non-renewable energy consumption; re, renewable energy consumption; ur, urbanization; eg, economic growth; c, constant.

The findings presented in Table 4 demonstrate that in both the first and second regimes, the consumption of non-renewable sources of energy, urbanization, and economic growth all contribute to greenhouse gas emissions, whereas the consumption of renewable sources of energy works to mitigate greenhouse gas emissions. It has been discovered that these results are largely compatible with those that are shown in Table 3, with the exception of a little variance in statistical significance and the magnitude of the coefficients. As a result, we may draw the conclusion that the results shown in Table 4 can be robust and reliable.

4.4. Causality Test

After cointegration has been assessed, the vector error correction model investigates the long-run and short-run Granger causal relationship between the highlighted variables and greenhouse gas emissions. Table 5 provides the findings.

Table 5. Results of vector error correction model.

Variable †	Δgg	Δne	Δre	Δur	Δeg	ecm−1
Δgg	-	11.603 ***	8.001 ***	6.592 ***	37.821 ***	12.513 ***
Δne	7.549 ***	-	2.084	3.272 *	2.545	7.444 ***
Δre	0.107	2.083	-	7.208 ***	0.662	0.509
Δur	0.592	3.272 *	7.208 ***	-	0.216	1.472
Δeg	7.821 ***	2.545	0.662	0.216	-	5.399 **

Note: *** significance at 1% level; ** significance at 5% level; * significance at 10% level. † Variable abbreviations: gg, greenhouse gas emissions; ne, non-renewable energy consumption; re, renewable energy consumption; ur, urbanization; eg, economic growth.

According to the findings that are presented in Table 5, it has been determined that short-run and two-way causal links between non-renewable energy consumption and greenhouse gas emissions are detected. Meanwhile, the coefficient of ecm−1 suggests that two-way causal links between non-renewable energy consumption and greenhouse gas emissions are also discovered. The coefficient of ecm−1, however, suggests that a long-run and two-way causal link between non-renewable energy consumption and greenhouse gas emission is found. In the same vein, it was shown that two-way causal links between greenhouse gas emissions and economic growth have been discovered, which can be demonstrated over time. The findings of Cao et al. [85], Barak [86], and Raihan and Tuspekova [87] provide credence to these results. Equally, it is observed that a short-run unidirectional causality flowing from the renewable energy consumption and urbanization to greenhouse gas emissions is detected. In the meantime, Rehman et al. [88] and Musah et al. [89] came to a result that was comparable to the one presented in this work.

4.5. Discussion

South Korean industries, including steel, petrochemicals, and others, are concerned about the unexpected increase in the need to reduce greenhouse gas emissions. The South Korean Ministry of Environment revised the road map for reducing greenhouse gas emissions in July of this year, significantly increasing the industry's emission reduction rate from 11.7% (based on the expected greenhouse gas emissions in 2030) to 20.5%. This change came about as a result of the government's commitment to addressing climate change. In this respect, the majority of those working in the sector are of the opinion that the goal of reducing emissions is overly idealistic since it does not take into consideration environmental protection technologies whose potential applications in business are not yet fully understood. In addition, the price of carbon emission rights for greenhouse gas emissions has also increased dramatically, which has resulted in a large increase in the amount of pressure that is placed on businesses.

Based on this context, this article explores the impacts of economic development, energy consumption, and urbanization on greenhouse gas emissions and provides numerous indicators of Korean environmental sustainability. This article explores the impacts of economic growth, energy consumption, and urbanization on greenhouse gas emissions and provides several pieces of evidence supporting Korean environmental sustainability. First, the use of fossil fuels in Korea is a barrier to achieving environmental sustainability. This is a suggestion that the Korean government needs to create new technologies or find alternatives that are more favorable to the environment in order to lessen the adverse consequences of the usage of fossil fuels as a source of energy. This suggestion is supported by Weiss et al. [90], and Imran et al. [91]. Second, consuming renewable energy is conducive to environmental sustainability. This demonstrates that the Korean government should spare no effort to support the growth of enterprises linked to renewable energy. Nematollahi and Kim [92], Jang et al. [93], and Lim et al. [94] all corroborate this assertion. Third, environmental sustainability is hindered by urbanization. As is well known, two-thirds reside in the Seoul circle. This article argues that the Korean government should enact laws to encourage balanced growth inside and outside of Seoul in order to improve environmental sustainability. This idea is backed by Shafique et al. [95], Song et al. [96], and Kim [97]. Fourth, rapid economic growth in South Korea is accompanied by significant greenhouse gas emissions. The government of Korea cautioned that fast economic progress should not come at the price of environmental damage. Therefore, the Korean government should choose a paradigm of sustainable economic development. Oryani et al. [98], Kim [99], and Zafar et al. [100] likewise endorse this proposal.

5. Conclusions

Maintaining environmental sustainability is one of the most difficult challenges across the world. As a result, using Korea as an example, this work explores the effects of economic growth, energy consumption, and urbanization on greenhouse gas emissions (a proxy for environmental sustainability) from the years 1990 to 2019. Using the autoregressive distributed lag technique to perform an empirical study, the findings reveal that non-renewable energy consumption, urbanization, and economic growth present a hazard to environmental sustainability because they positively impact greenhouse gas emissions. In contrast, renewable energy consumption supports environmental sustainability because it negatively influences greenhouse gas emissions. These findings remain constant over time. Furthermore, the findings of the causality test indicate that two-way causal links between greenhouse gas emissions, economic growth, and non-renewable energy consumption have been discovered over time, whereas unidirectional causal links between renewable energy consumption, urbanization, and greenhouse gas emissions have also been found.

This research offers several policy implications, all of which are based on the findings presented above. First, since non-renewable energy consumption inhibits environmental sustainability, the Korean government should either create new technologies to enhance utilization of non-renewable energy consumption or discover better alternatives, notwithstanding the need for non-renewable energy consumption for economic development. Second, since renewable energy consumption endorses environmental sustainability, the Korean government should contribute to the development of wind, tidal, and solar energy. Environmental sustainability may be maintained when these types of energy play a decisive part in economic expansion. Third, since urbanization is a barrier to environmental sustainability, the Korean government should optimize the population structure and narrow the gap between rural and urban regions. Fourth, the development of the economy comes with a significant rise in greenhouse gas emissions. Therefore, while strengthening its economy, the government of South Korea needs to wean itself off of its dependency on fossil fuels.

This study's discoveries contribute to the body of Korean literature that has previously been compiled on the aforementioned topic. First, the studies conducted by Park et al. [101] and Kim [97], which solely focus on the environmental consequences of renewable energy, are expanded upon by this work, which conducts an analysis of their effects on the environment from the standpoint of renewable energy and non-renewable energy. This will also assist the Korean government in allocating resources for energy use. Second, in Korea, excessive urbanization also poses a threat to environmental sustainability. According to statistics of the Korean Bureau of Statistics, two-thirds of Korea's population resides in Seoul, and the city's environment has created a significant strain. This paper's conclusion may be used as the most recent evidence to assist the Korean government in resolving the environmental pressure issue in Seoul and to enrich the current literature in Korea. Third, this work investigates not only the long-term effects of these highlighted variables on environmental sustainability but also their short-term effects. Compared to the investigations of Lee and Lim [102], Sakman et al. [103], and Hong et al. [104], this work enhances Korean current literature.

In conclusion, it should be mentioned that this work has a few limitations. On the basis of these limitations, corresponding directions for the future are supplied. First, the discussion of environmental sustainability in our work is only based on time-series data, which disregards the variations that exist across the provinces in Korea. As a consequence, the conclusions of this paper may not be entirely accurate. Therefore, future researcher may employ panel data to reexamine this issue, and they may acquire findings that are more intriguing as a result. Second, this study did not consider all of the possible control variables. When future researchers revisit this subject, they may take into account these missing control variables in their studies. It is possible to obtain outcomes that are more intriguing and robust. Third, since Korea is the sole country used as a case study in this article, the findings may not be applicable to other countries. Therefore, subsequent researchers will be able to increase the sample size and achieve findings that are more representative of the whole.

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References

1. Rasti-Barzoki, M.; Moon, I. A Game Theoretic Approach for Car Pricing and Its Energy Efficiency Level versus Governmental Sustainability Goals by Considering Rebound Effect: A Case Study of South Korea. *Appl. Energy* **2020**, *271*, 115196. [CrossRef]
2. Jin, S.-H. Home Appliances' Rebound Effects Estimated by a Modified Nonlinear Model: An Empirical Study in South Korea. *Energy Effic.* **2019**, *12*, 2187–2199. [CrossRef]
3. Choi, W.; Song, H.H. Well-to-Wheel Analysis on Greenhouse Gas Emission and Energy Use with Natural Gas in Korea. *Int. J. Life Cycle Assess.* **2014**, *19*, 850–860. [CrossRef]
4. Lee, J.; Kim, T.; Ellingsen, H.; Hognes, E.S.; Hwang, B. Energy Consumption and Greenhouse Gas Emission of Korean Offshore Fisheries. *J. Ocean Univ. China* **2018**, *17*, 675–682. [CrossRef]
5. Waheed, R.; Sarwar, S.; Wei, C. The Survey of Economic Growth, Energy Consumption and Carbon Emission. *Energy Rep.* **2019**, *5*, 1103–1115. [CrossRef]
6. Chang, X.; Ma, T.; Wu, R. Impact of Urban Development on Residents' Public Transportation Travel Energy Consumption in China: An Analysis of Hydrogen Fuel Cell Vehicles Alternatives. *Int. J. Hydrogen Energy* **2019**, *44*, 16015–16027. [CrossRef]
7. Park, J.; Yun, S.-J. Social Determinants of Residential Electricity Consumption in Korea: Findings from a Spatial Panel Model. *Energy* **2022**, *239*, 122272. [CrossRef]
8. Zaidi, S.A.H.; Hou, F.; Mirza, F.M. The Role of Renewable and Non-Renewable Energy Consumption in CO_2 Emissions: A Disaggregate Analysis of Pakistan. *Environ. Sci. Pollut. Res.* **2018**, *25*, 31616–31629. [CrossRef]
9. Zhang, B.; Wang, B.; Wang, Z. Role of Renewable Energy and Non-Renewable Energy Consumption on EKC: Evidence from Pakistan. *J. Clean. Prod.* **2017**, *156*, 855–864.
10. Boontome, P.; Therdyothin, A.; Chontanawat, J. Investigating the Causal Relationship between Non-Renewable and Renewable Energy Consumption, CO_2 Emissions and Economic Growth in Thailand. *Energy Procedia* **2017**, *138*, 925–930. [CrossRef]
11. Zhang, N.; Zhou, P.; Choi, Y. Energy Efficiency, CO_2 Emission Performance and Technology Gaps in Fossil Fuel Electricity Generation in Korea: A Meta-Frontier Non-Radial Directional Distance Functionanalysis. *Energy Policy* **2013**, *56*, 653–662. [CrossRef]
12. Oh, W.; Yoo, J. Long-Term Increases and Recent Slowdowns of CO_2 Emissions in Korea. *Sustainability* **2020**, *12*, 6924. [CrossRef]
13. Oh, I.; Wehrmeyer, W.; Mulugetta, Y. Decomposition Analysis and Mitigation Strategies of CO_2 Emissions from Energy Consumption in South Korea. *Energy Policy* **2010**, *38*, 364–377. [CrossRef]
14. Shin, H.-C.; Park, J.-W.; Kim, H.-S.; Shin, E.-S. Environmental and Economic Assessment of Landfill Gas Electricity Generation in Korea Using LEAP Model. *Energy Policy* **2005**, *33*, 1261–1270. [CrossRef]
15. Jin, S.H.; Bai, L.; Kim, J.Y.; Jeong, S.J.; Kim, K.S. Analysis of GHG Emission Reduction in South Korea Using a CO_2 Transportation Network Optimization Model. *Energies* **2017**, *10*, 1027. [CrossRef]
16. Sahoo, M.; Sahoo, J. Effects of Renewable and Non-Renewable Energy Consumption on CO_2 Emissions in India: Empirical Evidence from Disaggregated Data Analysis. *J. Public Aff.* **2022**, *22*, e2307. [CrossRef]
17. Nakhli, M.S.; Shahbaz, M.; Jebli, M.B.; Wang, S. Nexus between Economic Policy Uncertainty, Renewable & Non-Renewable Energy and Carbon Emissions: Contextual Evidence in Carbon Neutrality Dream of USA. *Renew. Energy* **2022**, *185*, 75–85.
18. Adebayo, T.S.; Rjoub, H. A New Perspective into the Impact of Renewable and Nonrenewable Energy Consumption on Environmental Degradation in Argentina: A Time–Frequency Analysis. *Environ. Sci. Pollut. Res.* **2022**, *29*, 16028–16044. [CrossRef]
19. Amin, N.; Song, H.; Shabbir, M.S. What Factors Contribute to Environmental Degradation in G11 Economies? Emphasizing the Importance of Renewable and Non-Renewable Energy Sources. *Int. J. Sustain. Dev. World Ecol.* **2022**, *29*, 472–482. [CrossRef]

20. Imran, M.; Ali, S.; Shahwan, Y.; Zhang, J.; Al-Swiety, I.A. Analyzing the Effects of Renewable and Nonrenewable Energy Usage and Technological Innovation on Environmental Sustainability: Evidence from QUAD Economies. *Sustainability* **2022**, *14*, 15552. [CrossRef]
21. He, Y.; Zhang, Z. Non-Renewable and Renewable Energies, and COVID-19 Pandemic: Do They Matter for China's Environmental Sustainability? *Energies* **2022**, *15*, 7143. [CrossRef]
22. Jin, L.; Chang, Y.; Wang, M.; Zheng, X.; Yang, J.; Gu, J. The Dynamics of CO_2 Emissions, Energy Consumption, and Economic Development: Evidence from the Top 28 Greenhouse Gas Emitters. *Environ. Sci. Pollut. Res.* **2022**, *29*, 36565–36574. [CrossRef]
23. Shafiei, S.; Salim, R.A. Non-Renewable and Renewable Energy Consumption and CO_2 Emissions in OECD Countries: A Comparative Analysis. *Energy Policy* **2014**, *66*, 547–556. [CrossRef]
24. Waheed, R.; Chang, D.; Sarwar, S.; Chen, W. Forest, Agriculture, Renewable Energy, and CO_2 Emission. *J. Clean. Prod.* **2018**, *172*, 4231–4238. [CrossRef]
25. Jun, S.; Lee, S.; Park, J.-W.; Jeong, S.-J.; Shin, H.-C. The Assessment of Renewable Energy Planning on CO_2 Abatement in South Korea. *Renew. Energy* **2010**, *35*, 471–477. [CrossRef]
26. Cho, S.; Kim, J. Feasibility and Impact Analysis of a Renewable Energy Source (RES)-Based Energy System in Korea. *Energy* **2015**, *85*, 317–328. [CrossRef]
27. Koc, S.; Bulus, G.C. Testing Validity of the EKC Hypothesis in South Korea: Role of Renewable Energy and Trade Openness. *Environ. Sci. Pollut. Res.* **2020**, *27*, 29043–29054. [CrossRef]
28. Adebayo, T.S.; Coelho, M.F.; Onbaşıoğlu, D.Ç.; Rjoub, H.; Mata, M.N.; Carvalho, P.V.; Rita, J.X.; Adeshola, I. Modeling the Dynamic Linkage between Renewable Energy Consumption, Globalization, and Environmental Degradation in South Korea: Does Technological Innovation Matter? *Energies* **2021**, *14*, 4265. [CrossRef]
29. Nam, K.; Hwangbo, S.; Yoo, C. A Deep Learning-Based Forecasting Model for Renewable Energy Scenarios to Guide Sustainable Energy Policy: A Case Study of Korea. *Renew. Sustain. Energy Rev.* **2020**, *122*, 109725. [CrossRef]
30. Jebli, M.B.; Farhani, S.; Guesmi, K. Renewable Energy, CO_2 Emissions and Value Added: Empirical Evidence from Countries with Different Income Levels. *Struct. Chang. Econ. Dyn.* **2020**, *53*, 402–410. [CrossRef]
31. Dogan, E.; Seker, F. Determinants of CO_2 Emissions in the European Union: The Role of Renewable and Non-Renewable Energy. *Renew. Energy* **2016**, *94*, 429–439. [CrossRef]
32. Razmjoo, A.; Kaigutha, L.G.; Rad, M.V.; Marzband, M.; Davarpanah, A.; Denai, M. A Technical Analysis Investigating Energy Sustainability Utilizing Reliable Renewable Energy Sources to Reduce CO_2 Emissions in a High Potential Area. *Renew. Energy* **2021**, *164*, 46–57. [CrossRef]
33. Imran, M.; Khan, S.; Zaman, K.; Khan, H.u.R.; Rashid, A. Assessing Green Solutions for Indoor and Outdoor Environmental Quality: Sustainable Development Needs Renewable Energy Technology. *Atmosphere* **2022**, *13*, 1904. [CrossRef]
34. Sadorsky, P. The Effect of Urbanization on CO_2 Emissions in Emerging Economies. *Energy Econ.* **2014**, *41*, 147–153. [CrossRef]
35. Wang, S.; Li, G.; Fang, C. Urbanization, Economic Growth, Energy Consumption, and CO_2 Emissions: Empirical Evidence from Countries with Different Income Levels. *Renew. Sustain. Energy Rev.* **2018**, *81*, 2144–2159. [CrossRef]
36. Martínez-Zarzoso, I.; Maruotti, A. The Impact of Urbanization on CO_2 Emissions: Evidence from Developing Countries. *Ecol. Econ.* **2011**, *70*, 1344–1353. [CrossRef]
37. Zhang, C.; Lin, Y. Panel Estimation for Urbanization, Energy Consumption and CO_2 Emissions: A Regional Analysis in China. *Energy Policy* **2012**, *49*, 488–498. [CrossRef]
38. Poumanyvong, P.; Kaneko, S. Does Urbanization Lead to Less Energy Use and Lower CO_2 Emissions? A Cross-Country Analysis. *Ecol. Econ.* **2010**, *70*, 434–444. [CrossRef]
39. Al-Mulali, U.; Fereidouni, H.G.; Lee, J.Y.; Sab, C.N.B.C. Exploring the Relationship between Urbanization, Energy Consumption, and CO_2 Emission in MENA Countries. *Renew. Sustain. Energy Rev.* **2013**, *23*, 107–112. [CrossRef]
40. Zhu, H.-M.; You, W.-H.; Zeng, Z. Urbanization and CO_2 Emissions: A Semi-Parametric Panel Data Analysis. *Econ. Lett.* **2012**, *117*, 848–850. [CrossRef]
41. Acheampong, A.O. Economic Growth, CO_2 Emissions and Energy Consumption: What Causes What and Where? *Energy Econ.* **2018**, *74*, 677–692. [CrossRef]
42. Lotfalipour, M.R.; Falahi, M.A.; Ashena, M. Economic Growth, CO_2 Emissions, and Fossil Fuels Consumption in Iran. *Energy* **2010**, *35*, 5115–5120. [CrossRef]
43. Mardani, A.; Streimikiene, D.; Cavallaro, F.; Loganathan, N.; Khoshnoudi, M. Carbon Dioxide (CO_2) Emissions and Economic Growth: A Systematic Review of Two Decades of Research from 1995 to 2017. *Sci. Total Environ.* **2019**, *649*, 31–49. [CrossRef]
44. Heidari, H.; Katircioğlu, S.T.; Saeidpour, L. Economic Growth, CO_2 Emissions, and Energy Consumption in the Five ASEAN Countries. *Int. J. Electr. Power Energy Syst.* **2015**, *64*, 785–791. [CrossRef]
45. Saidi, K.; Hammami, S. The Impact of CO_2 Emissions and Economic Growth on Energy Consumption in 58 Countries. *Energy Rep.* **2015**, *1*, 62–70. [CrossRef]
46. Ozturk, I.; Acaravci, A. CO_2 Emissions, Energy Consumption and Economic Growth in Turkey. *Renew. Sustain. Energy Rev.* **2010**, *14*, 3220–3225. [CrossRef]
47. Saint Akadiri, S.; Bekun, F.V.; Sarkodie, S.A. Contemporaneous Interaction between Energy Consumption, Economic Growth and Environmental Sustainability in South Africa: What Drives What? *Sci. Total Environ.* **2019**, *686*, 468–475. [CrossRef]

48. Kirikkaleli, D.; Adebayo, T.S. Do Renewable Energy Consumption and Financial Development Matter for Environmental Sustainability? New Global Evidence. *Sustain. Dev.* **2021**, *29*, 583–594. [CrossRef]
49. Xue, C.; Shahbaz, M.; Ahmed, Z.; Ahmad, M.; Sinha, A. Clean Energy Consumption, Economic Growth, and Environmental Sustainability: What Is the Role of Economic Policy Uncertainty? *Renew. Energy* **2022**, *184*, 899–907. [CrossRef]
50. Ulucak, R.; Ozcan, B. Relationship between Energy Consumption and Environmental Sustainability in OECD Countries: The Role of Natural Resources Rents. *Resour. Policy* **2020**, *69*, 101803. [CrossRef]
51. Miao, Y.; Razzaq, A.; Adebayo, T.S.; Awosusi, A.A. Do Renewable Energy Consumption and Financial Globalisation Contribute to Ecological Sustainability in Newly Industrialized Countries? *Renew. Energy* **2022**, *187*, 688–697. [CrossRef]
52. Akadiri, S.S.; Adebayo, T.S. Asymmetric Nexus among Financial Globalization, Non-Renewable Energy, Renewable Energy Use, Economic Growth, and Carbon Emissions: Impact on Environmental Sustainability Targets in India. *Environ. Sci. Pollut. Res.* **2021**, *29*, 16311–16323. [CrossRef] [PubMed]
53. Li, Y.; Li, Y.; Zhou, Y.; Shi, Y.; Zhu, X. Investigation of a Coupling Model of Coordination between Urbanization and the Environment. *J. Environ. Manag.* **2012**, *98*, 127–133. [CrossRef]
54. Shahbaz, M.; Loganathan, N.; Muzaffar, A.T.; Ahmed, K.; Jabran, M.A. How Urbanization Affects CO_2 Emissions in Malaysia? The Application of STIRPAT Model. *Renew. Sustain. Energy Rev.* **2016**, *57*, 83–93. [CrossRef]
55. Behera, S.R.; Dash, D.P. The Effect of Urbanization, Energy Consumption, and Foreign Direct Investment on the Carbon Dioxide Emission in the SSEA (South and Southeast Asian) Region. *Renew. Sustain. Energy Rev.* **2017**, *70*, 96–106. [CrossRef]
56. Zhang, L.; Li, Z.; Kirikkaleli, D.; Adebayo, T.S.; Adeshola, I.; Akinsola, G.D. Modeling CO_2 Emissions in Malaysia: An Application of Maki Cointegration and Wavelet Coherence Tests. *Environ. Sci. Pollut. Res.* **2021**, *28*, 26030–26044. [CrossRef]
57. Özokcu, S.; Özdemir, Ö. Economic Growth, Energy, and Environmental Kuznets Curve. *Renew. Sustain. Energy Rev.* **2017**, *72*, 639–647. [CrossRef]
58. He, Y.; Li, X.; Huang, P.; Wang, J. Exploring the Road toward Environmental Sustainability: Natural Resources, Renewable Energy Consumption, Economic Growth, and Greenhouse Gas Emissions. *Sustainability* **2022**, *14*, 1579. [CrossRef]
59. He, Y. Renewable and Non-Renewable Energy Consumption and Trade Policy: Do They Matter for Environmental Sustainability? *Energies* **2022**, *15*, 3559. [CrossRef]
60. He, Y.; Huang, P. Exploring the Forms of the Economic Effects of Renewable Energy Consumption: Evidence from China. *Sustainability* **2022**, *14*, 8212. [CrossRef]
61. Dickey, D.A.; Fuller, W.A. Distribution of the Estimators for Autoregressive Time Series with a Unit Root. *J. Am. Stat. Assoc.* **1979**, *74*, 427–431.
62. Phillips, P.C.; Perron, P. Testing for a Unit Root in Time Series Regression. *Biometrika* **1988**, *75*, 335–346. [CrossRef]
63. Perron, P. The Great Crash, the Oil Price Shock, and the Unit Root Hypothesis. *Econom. J. Econom. Soc.* **1989**, *57*, 1361–1401. [CrossRef]
64. Baum, C.F. A Review of Stata 8.1 and Its Time Series Capabilities. *Work. Pap. Econ.* **2003**, *23*, 1–17. [CrossRef]
65. Zivot, E.; Andrews, D.W.K. Further Evidence on the Great Crash, the Oil-Price Shock, and the Unit-Root Hypothesis. *J. Bus. Econ. Stat.* **2002**, *20*, 25–44. [CrossRef]
66. Otero, J.; Smith, J. Testing for Cointegration: Power versus Frequency of Observation—Further Monte Carlo Results. *Econ. Lett.* **2000**, *67*, 5–9. [CrossRef]
67. Zhou, S. The Power of Cointegration Tests versus Data Frequency and Time Spans. *South. Econ. J.* **2001**, *67*, 906–921.
68. Pesaran, M.H.; Shin, Y. An Autoregressive Distributed Lag Modelling Approach to Cointegration Analysis. In *Econometrics and Economic Theory in the 20th Century*; Cambridge University Press: Cambridge, UK, 1995.
69. Engle, R.F.; Granger, C.W. Co-Integration and Error Correction: Representation, Estimation, and Testing. *Econ. J. Econ. Soc.* **1987**, *55*, 251–276. [CrossRef]
70. Tsangas, M.; Zorpas, A.A.; Jeguirim, M.; Limousy, L. Cyprus Energy Resources and Their Potential to Increase Sustainability. In Proceedings of the IEEE 2018 9th International Renewable Energy Congress (IREC), Hammamet, Tunisia, 20–22 March 2018; pp. 1–7.
71. Destek, M.A.; Aslan, A. Renewable and Non-Renewable Energy Consumption and Economic Growth in Emerging Economies: Evidence from Bootstrap Panel Causality. *Renew. Energy* **2017**, *111*, 757–763. [CrossRef]
72. Djellouli, N.; Abdelli, L.; Elheddad, M.; Ahmed, R.; Mahmood, H. The Effects of Non-Renewable Energy, Renewable Energy, Economic Growth, and Foreign Direct Investment on the Sustainability of African Countries. *Renew. Energy* **2022**, *183*, 676–686. [CrossRef]
73. Karytsas, S.; Vardopoulos, I.; Theodoropoulou, E. Factors Affecting Sustainable Market Acceptance of Residential Microgeneration Technologies. A Two Time Period Comparative Analysis. *Energies* **2019**, *12*, 3298. [CrossRef]
74. Amponsah, N.Y.; Troldborg, M.; Kington, B.; Aalders, I.; Hough, R.L. Greenhouse Gas Emissions from Renewable Energy Sources: A Review of Lifecycle Considerations. *Renew. Sustain. Energy Rev.* **2014**, *39*, 461–475. [CrossRef]
75. Lyeonov, S.; Pimonenko, T.; Bilan, Y.; Štreimikienė, D.; Mentel, G. Assessment of Green Investments' Impact on Sustainable Development: Linking Gross Domestic Product per Capita, Greenhouse Gas Emissions and Renewable Energy. *Energies* **2019**, *12*, 3891. [CrossRef]
76. Ragazou, K.; Garefalakis, A.; Zafeiriou, E.; Passas, I. Agriculture 5.0: A New Strategic Management Mode for a Cut Cost and an Energy Efficient Agriculture Sector. *Energies* **2022**, *15*, 3113. [CrossRef]

77. Luo, C.; Posen, I.D.; Hoornweg, D.; MacLean, H.L. Modelling Future Patterns of Urbanization, Residential Energy Use and Greenhouse Gas Emissions in Dar Es Salaam with the Shared Socio-Economic Pathways. *J. Clean. Prod.* **2020**, *254*, 119998. [CrossRef]
78. Liobikienė, G.; Butkus, M. Scale, Composition, and Technique Effects through Which the Economic Growth, Foreign Direct Investment, Urbanization, and Trade Affect Greenhouse Gas Emissions. *Renew. Energy* **2019**, *132*, 1310–1322. [CrossRef]
79. Hsiao, C.-M. Economic Growth, CO_2 Emissions Quota and Optimal Allocation under Uncertainty. *Sustainability* **2022**, *14*, 8706. [CrossRef]
80. Mignamissi, D.; Djeufack, A. Urbanization and CO_2 Emissions Intensity in Africa. *J. Environ. Plan. Manag.* **2022**, *65*, 1660–1684. [CrossRef]
81. Fatima, T.; Mentel, G.; Doğan, B.; Hashim, Z.; Shahzad, U. Investigating the Role of Export Product Diversification for Renewable, and Non-Renewable Energy Consumption in GCC (Gulf Cooperation Council) Countries: Does the Kuznets Hypothesis Exist? *Environ. Dev. Sustain.* **2022**, *24*, 8397–8417. [CrossRef]
82. Sun, D.; Cai, S.; Yuan, X.; Zhao, C.; Gu, J.; Chen, Z.; Sun, H. Decomposition and Decoupling Analysis of Carbon Emissions from Agricultural Economic Growth in China's Yangtze River Economic Belt. *Environ. Geochem. Health* **2022**, *44*, 2987–3006. [CrossRef]
83. Paris, B.; Vandorou, F.; Balafoutis, A.T.; Vaiopoulos, K.; Kyriakarakos, G.; Manolakos, D.; Papadakis, G. Energy Use in Open-Field Agriculture in the EU: A Critical Review Recommending Energy Efficiency Measures and Renewable Energy Sources Adoption. *Renew. Sustain. Energy Rev.* **2022**, *158*, 112098. [CrossRef]
84. Kartal, M.T. The Role of Consumption of Energy, Fossil Sources, Nuclear Energy, and Renewable Energy on Environmental Degradation in Top-Five Carbon Producing Countries. *Renew. Energy* **2022**, *184*, 871–880. [CrossRef]
85. Cao, H.; Khan, M.K.; Rehman, A.; Dagar, V.; Oryani, B.; Tanveer, A. Impact of Globalization, Institutional Quality, Economic Growth, Electricity and Renewable Energy Consumption on Carbon Dioxide Emission in OECD Countries. *Environ. Sci. Pollut. Res.* **2022**, *29*, 24191–24202. [CrossRef]
86. Barak, D. The Impact of Income Inequality, Renewable Energy Consumption, Non-Renewable Energy Consumption and Per Capita Income on Poverty: Evidence from BRICS Economies. *Ekonomika* **2022**, *101*, 62–83. [CrossRef]
87. Raihan, A.; Tuspekova, A. Toward a Sustainable Environment: Nexus between Economic Growth, Renewable Energy Use, Forested Area, and Carbon Emissions in Malaysia. *Resour. Conserv. Recycl. Adv.* **2022**, *15*, 200096. [CrossRef]
88. Rehman, A.; Ma, H.; Ozturk, I.; Ulucak, R. Sustainable Development and Pollution: The Effects of CO_2 Emission on Population Growth, Food Production, Economic Development, and Energy Consumption in Pakistan. *Environ. Sci. Pollut. Res.* **2022**, *29*, 17319–17330. [CrossRef]
89. Musah, M.; Owusu-Akomeah, M.; Boateng, F.; Iddris, F.; Mensah, I.A.; Antwi, S.K.; Agyemang, J.K. Long-Run Equilibrium Relationship between Energy Consumption and CO_2 Emissions: A Dynamic Heterogeneous Analysis on North Africa. *Environ. Sci. Pollut. Res.* **2022**, *29*, 10416–10433. [CrossRef]
90. Weiss, M.; Neelis, M.; Blok, K.; Patel, M. Non-Energy Use of Fossil Fuels and Resulting Carbon Dioxide Emissions: Bottom–up Estimates for the World as a Whole and for Major Developing Countries. *Clim. Chang.* **2009**, *95*, 369–394. [CrossRef]
91. Imran, M.; Park, B.-S.; Kim, H.-J.; Lee, D.-H.; Usman, M. Economic Assessment of Greenhouse Gas Reduction through Low-Grade Waste Heat Recovery Using Organic Rankine Cycle (ORC). *J. Mech. Sci. Technol.* **2015**, *29*, 835–843. [CrossRef]
92. Nematollahi, O.; Kim, K.C. A Feasibility Study of Solar Energy in South Korea. *Renew. Sustain. Energy Rev.* **2017**, *77*, 566–579. [CrossRef]
93. Jang, N.; Cho, I.; Jeon, H.; Koo, J. Optimization of the Wood Pellet Supply during the Continued Increase of the Renewable Energy's Proportion in the Energy Portfolio. *Korean J. Chem. Eng.* **2022**, *39*, 2028–2033. [CrossRef] [PubMed]
94. Lim, J.Y.; How, B.S.; Rhee, G.; Hwangbo, S.; Yoo, C.K. Transitioning of Localized Renewable Energy System towards Sustainable Hydrogen Development Planning: P-Graph Approach. *Appl. Energy* **2020**, *263*, 114635. [CrossRef]
95. Shafique, M.; Azam, A.; Rafiq, M.; Luo, X. Evaluating the Relationship between Freight Transport, Economic Prosperity, Urbanization, and CO_2 Emissions: Evidence from Hong Kong, Singapore, and South Korea. *Sustainability* **2020**, *12*, 10664. [CrossRef]
96. Song, M.-J.; Seo, Y.-J.; Lee, H.-Y. The Dynamic Relationship between Industrialization, Urbanization, CO_2 Emissions, and Transportation Modes in Korea: Empirical Evidence from Maritime and Air Transport. *Transportation* **2022**, 1–27. [CrossRef] [PubMed]
97. Kim, S. The Effects of Foreign Direct Investment, Economic Growth, Industrial Structure, Renewable and Nuclear Energy, and Urbanization on Korean Greenhouse Gas Emissions. *Sustainability* **2020**, *12*, 1625. [CrossRef]
98. Oryani, B.; Moridian, A.; Rezania, S.; Vasseghian, Y.; Bagheri, M.; Shahzad, K. Asymmetric Impacts of Economic Uncertainties and Energy Consumption on the Ecological Footprint: Implications apropos Structural Transformation in South Korea. *Fuel* **2022**, *322*, 124180. [CrossRef]
99. Kim, S. CO_2 Emissions, Foreign Direct Investments, Energy Consumption, and GDP in Developing Countries: A More Comprehensive Study Using Panel Vector Error Correction Model. *Korean Econ. Rev.* **2019**, *35*, 5–24.
100. Zafar, M.W.; Saleem, M.M.; Destek, M.A.; Caglar, A.E. The Dynamic Linkage between Remittances, Export Diversification, Education, Renewable Energy Consumption, Economic Growth, and CO_2 Emissions in Top Remittance-Receiving Countries. *Sustain. Dev.* **2022**, *30*, 165–175. [CrossRef]

101. Park, C.-H.; Ko, Y.-J.; Kim, J.-H.; Hong, H. Greenhouse Gas Reduction Effect of Solar Energy Systems Applicable to High-Rise Apartment Housing Structures in South Korea. *Energies* **2020**, *13*, 2568. [CrossRef]
102. Lee, J.H.; Lim, S. The Selection of Compact City Policy Instruments and Their Effects on Energy Consumption and Greenhouse Gas Emissions in the Transportation Sector: The Case of South Korea. *Sustain. Cities Soc.* **2018**, *37*, 116–124. [CrossRef]
103. Salman, M.; Long, X.; Dauda, L.; Mensah, C.N. The Impact of Institutional Quality on Economic Growth and Carbon Emissions: Evidence from Indonesia, South Korea and Thailand. *J. Clean. Prod.* **2019**, *241*, 118331. [CrossRef]
104. Hong, J.-W.; Hong, J.; Kwon, E.E.; Yoon, D. Temporal Dynamics of Urban Heat Island Correlated with the Socio-Economic Development over the Past Half-Century in Seoul, Korea. *Environ. Pollut.* **2019**, *254*, 112934. [CrossRef] [PubMed]