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Revisiting the Relation between Renewable Electricity and Economic Growth: A Renewable–Growth Hypothesis

Minyoung Yang and Jinsoo Kim *

Department of Earth Resources and Environmental Engineering, Hanyang University, 222 Wangsimni-ro, Seongdong-gu, Seoul 04763, Korea; yminy94@hanyang.ac.kr
* Correspondence: jinsookim@hanyang.ac.kr; Tel.: +82-2-2220-2241

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Abstract: Global concern about the climate crisis has incited movements for switching to renewable electricity. Renewable electricity can contribute to economic growth as an input factor (electricity generation) and also as an industry (renewable manufacturing). We introduce a new hypothesis, the renewable–growth hypothesis, to investigate the role of the renewable manufacturing industry in the energy–growth nexus study. To test the hypothesis, we select a target country group using the market share of the renewable manufacturing industry and conduct the Granger causality test for solar photovoltaic and wind power. The autoregressive distributed lag bounds testing approach is applied for the causality test. The results show that renewable electricity Granger causes economic growth in target countries, which supports the renewable–growth hypothesis. However, the hypothesis did not hold in countries that export renewable power facilities more than they install them for domestic demand. We believe that the renewable–growth hypothesis would be secured soon if renewable electricity expands broadly over the world.

Keywords: renewable–growth hypothesis; renewable electricity; economic growth; renewable manufacturing; energy–growth nexus

1. Introduction

International attention to global warming comprises the global effort for carbon reduction. However, if we keep our pledges at the current level, the world's temperature will increase to almost twice the limit referred to in the Paris Agreement by the end of the century. Climate change is now referred to as the "climate crisis" [1]. This phenomenon also draws attention to the topic of energy, particularly in the electricity industry. As part of that, many countries have displayed their transition to renewable energy from fossil fuels, which are considered the main source of carbon emissions. However, many governments, especially those in Asia, are still using coal-fired power stations. Even worse, the demand growth for gas as an alternative to coal is emerging [2]. Transitioning to renewable energy is a means for solving problems caused by the climate crisis.

Indeed, renewable energy accounted for an estimated 18.1% of total final energy consumption (TFEC) in 2017. Modern renewables composed 10.6% of TFEC, with an estimated 4.4% growth in demand compared to 2016. Particularly in the power sector, renewable energy has grown to account for more than 33% of the world's total installed power-generating capacity in 2018. Solar photovoltaics (PV) comprises 55% of renewable capacity, after the additional installation of around 100 gigawatts in 2018, and is followed by wind power (28%) [3].

Economic development and sustainability are important not only for carbon reduction but also for the global trend promoting renewable energies [4–6]. Developed economies promote renewable sources to strengthen the energy security of supply and control their greenhouse gas emissions [7]. Similarly, understanding the causal relationship between renewable energy and economic growth is significant for a country's economic development and as the basis for policymakers. Therefore, extensive research has been conducted on the relationship between them. In the 1980s, many studies investigated the relationship between energy consumption and economic growth [8]. "Energy–growth nexus" is a term referring to the link between energy consumption and economic growth. The energy–growth nexus has reached a more disaggregated level over time [9].

An analysis of renewable energy growth is needed considering the described circumstances. The facility cost of renewable electricity accounts for a higher percentage in power generation costs compared to non-renewable energy [10]. This means that, if we increase solar facilities, the demand for all sectors related to them also increases. This might lead to positive effects on economic growth. Furthermore, renewable electricity is capital intensive and has a value-added effect. According to Ernst & Young [11], the solar industry in the European Union 28 represented more than 81,000 full-time equivalents and more than EUR 4600 million gross value-added (GVA). They mentioned the installed capacity has a significant impact on job and GVA creation because there is a direct impact on manufacturing and services needed. Thus, the increasing demand for renewable electricity has a positive effect on such industries and is related to economic growth.

However, if a country generally imports equipment and produces its own electricity, renewable electricity demand has less or no positive impact on economic growth. Given the cost structure of the renewable electricity industry, growth is driven by demand growth in a related facility. It has a different growth mechanism when a country simply purchases equipment. If so, it is likely to have a positive impact on the economy of the country producing that facility. This means that if demand for renewable electricity increases, there is no induced effect like great value-added or additional demand in other industries or there is only an impact on the country's imports concerning the overall facility. Therefore, the relationship between renewable electricity demand and economic growth may not be evident in these countries.

There are four hypotheses on the energy–growth nexus considering the number of cases that could be the result of the analysis [12]. First, the "neutrality hypothesis" implies the absence of a causal relationship between energy consumption and GDP. The second one, the "conservation hypothesis," suggests that energy conservation policies may be implemented with little or no adverse effect on economic growth. In the third one, the "growth hypothesis" means that energy consumption is important for economic growth. The last one that implies bidirectional causality between the two factors is the "feedback hypothesis." It is possible to derive energy policy through an analysis of the above hypothesis. The energy conservation policy means reducing energy consumption for economic growth. If a specific country's energy–growth nexus follows the growth hypothesis, energy conservation policies may have an adverse impact on economic growth. However, if under the neutrality hypothesis, energy conservation policies may not have much impact. The main purpose of the energy–growth nexus study is to examine which hypothesis is investigated in a specific country or group of countries. The results of the energy–growth nexus study have yielded mixed results within hypotheses. Existing hypotheses are focused on energy itself and do not consider specific industries. Therefore, the existing hypothesis is not enough to cover the impact of renewable energy manufacturing.

Due to the feature originating from the renewable manufacturing industry, renewable electricity and economic growth will show a positive relationship. Thus, this study tries to fill the gap with a new hypothesis, which is the "renewable–growth hypothesis." We analyze the time-series data of countries to confirm the renewable–growth relationship. The main contributions of this study are as follows. First, this study investigates if the development of the renewable energy generation sector has a positive effect on economic growth considering the features of the renewable power sector. Second, a new perspective of renewable–growth hypothesis is proposed, and the national group supporting the analysis is established. This makes it possible to draw implications for the policy direction of fostering the renewable electricity industry. Furthermore, this study presents the issues to promote further studies.

The paper is organized as follows. Section 2 provides a review of the literature. Section 3 describes the countries to be analyzed and the data to be used for analysis and explains the model and methodology. Section 4 provides empirical results. Section 5 concludes the paper and provides remarks and policy implications.

2. Literature Review

2.1. Overview of Energy–Growth Nexus

The energy–growth nexus has been studied in order to confirm the direction of the causality and its hypothesis has been well developed via various studies (see Table 1). They can be divided into country-specific studies [13–16] and multi-country studies [17–19]. Some of the studies attempted to examine the causal relationship in the energy–growth nexus in both developed and developing countries or by using different period data [8–10,18,20–22]. A study can be conducted for a specific research purpose. Pao and Fu [23] tried to investigate the relationship between economic growth and energy consumption in Brazil. Contrary to the previous study, this study covered various types of energy. They found mixed results: A conservation hypothesis between non-renewable energy consumption and economic growth, a growth hypothesis between non-hydroelectric renewable energy consumption and economic growth, and a feedback hypothesis between economic growth and total renewable energy consumption. Others focused more on the causal relationship between economic growth and energy consumption [24,25]. Apergis and Danuletiu [24] examined the relationship between economic growth and renewable energy consumption for 80 countries using the long-run causality test. They concluded that there is a bidirectional causality between renewable energy consumption and economic growth in the long run. Kazar and Kazar [25] investigated the relationship between development and renewable electricity net generation values for 154 countries with a panel analysis. They found the presence of bidirectional causality in the short run and that the causal relationship differs both in the short run and long run depending on the human development level.

2.2. Electricity and Economic Growth

The energy–growth nexus has been studied in various countries and on a more disaggregated level [9]. In addition to the interest in climate change, many countries and policymakers have tried to implement an electricity conservation policy. The confirmed results of research have been used as a basis for implementing such a policy and to establish the right policy direction for the country. The electricity–growth nexus for a single country has been studied and developed for that reason. Ramcharran [26] studied the electricity–growth nexus in Jamaica and found that the country is energy dependent. Ghosh [27] and Narayan and Smyth [28] investigated energy consumption and economic growth in India and Australia, respectively. They found Granger causality from economic growth to electricity consumption in both countries. In addition, research is being conducted in various countries such as Korea [29], Bangladesh [30], Cyprus [31], China [32], Turkey [33], Malaysia [34], Lebanon [35], and Nigeria [36]. However, due to the omitted variable bias, the studies that use only energy consumption and economic growth as variables should be interpreted with caution. In that context, some studies have attempted to make econometric transformations by adding employment variables to the bivariate model [37] or setting up the model reflecting the structural beaks [38]. Lorde et al. [39] constructed a multivariate model using the neoclassical production model to examine the economic theory. In various studies, bivariate and multivariate models were analyzed, in order or simultaneously. The impact on economic growth has been studied for the implementation of national power-related policies until recently [40–43].

An electricity–growth nexus may be established by setting up a group of countries depending on the research purpose. Yoo [44] analyzed the relationship between electricity consumption and economic growth in ASEAN countries for similar characteristics in the electricity sector. This study tried to confirm the relationship between electricity consumption and economic growth within a similar-featured group but with some differences in terms of investment in the power sector. Each of the four countries showed similar results with the two countries, respectively. The Organization of the Petroleum Exporting Countries (OPEC) is expected to be greatly influenced by energy conservation due to the characteristics of oil-producing countries. However, despite the obvious similarities, the results vary depending on the model and the time period [45,46]. This "no consensus" feature of the electricity–growth nexus was observed among the countries in the group even when the econometric method was modified. Acaravci and Ozturk [47] emphasized that they have results that conflict with the existing literature through the identification of the Granger causality of panel data. At the same time, they stated and emphasized that this issue deserves more attention and needs further research.

Some studies approach the characteristics of a country from an economic perspective. Apergis and Payne [48] analyzed a total of 88 countries using the panel vector error correction models based on the level of economic income. The study showed different results depending on whether a country was assessed in terms of the short run or the long run and also depending on its development level. In the long run, bidirectional causality exists in both high-income and upper-middle-income panels and lower-middle-income country panels. The growth hypothesis is satisfied in lower-middle-income country panels and low-income country panels in the short run. Even in the same group, mixed results were observed according to the short-run and long-run views [49], but some studies show a consensus between studies analyzing the same country [50].

Over time, research has been further disaggregated in various aspects, with national concerns shifting to energy transitions rather than just energy conservation. As a result, studies distinguishing renewable and non-renewable electricity from total electricity have begun [51–57]. Ibrahiem [51] mentions the limitations of the structure of the Egyptian electricity market, such as the crude-oil shortage, the need for renewable growth, or the transition on power mix. Apergis and Payne [52] conducted the panel causality test for the emerging market, including Egypt. Apergis and Payne [53] extend their work by examining the causal dynamics between renewable and non-renewable electricity consumption and economic growth in Central America. They show the negative bidirectional causality between renewable and non-renewable electricity consumption and conclude that the cause of this is that imported petroleum products raise concerns about the security of the region's energy supply. One of their contributions is their investigation of the negative bidirectional causality between renewable and non-renewable electricity consumption. They believe that this is due to imported petroleum products raising concerns about the security of the region's energy supply.

The analysis of renewable electricity is relevant to climate change and policies for global warming mitigation. Based on the results of the study, each country is recommended to increase its investment in renewable energy projects and vice versa (Table 1). According to the confirmed results of Al-mulali et al. [54], they recommended that Latin American countries should encourage not only the investment for renewable energy projects but also reduction in the role of non-renewable sources in electricity consumption. In recent years, these recommendations have been implemented in a way analysis of non-standard Granger causality [55–57]. In this way, it is possible to confirm the effect of specific energy sources [55] or conduct the analysis not only on aggregate electricity models but also those disaggregated into renewable and non-renewable models [57]. Despite the development of the research scope by the economic and econometric approach, the field of energy–growth nexus must still be investigated not only in terms of methodology but also in economics or policy.

Table 1. The previous study-related electricity growth nexus.

Author	Country	Period	Methodology	Finding
Ramcharran (1990) [26]	Jamaica	1970–1986	Granger causality	EC → Y
Ghosh (2002) [27]	India	1950–1997	Granger causality	Y → EC
Narayan and Smyth (2005) [28]	Australia	1966–1999	Multivariate Granger causality	Y → EC
Yoo (2005) [29]	Korea	1970–2002	Cointegration VECM (vector error correction model) Brown parameter stability test	Y ⇔ EC
Yoo (2006) [44]	4 countries	1971–2002	Hsiao’s version of Granger causality Standard Granger causality test	Y → EC (Thailand, Indonesia) EC → Y (Singapore, Malaysia)
Mozumder and Marathe (2007) [30]	Bangladesh	1971–1999	Cointegration VECM	Y → EC
Zachariadis and Pashourtidou (2007) [31]	Cyprus	1960–2004	Cointegration Granger causality VECM	Y ⇔ EC
Yuan et al., (2007) [32]	China	1978–2004	Cointegration Hodrick–Prescott (HP) filter Granger causality	EC → Y
Squalli (2007) [45]	All OPEC members	1980–2003	Cointegration ARDL (autoregressive distributed lag) Bounds Test Toda and Yamamoto causality test	Y → EC (Indonesia, Libya, Iraq, Algeria,) EC → Y (Kuwait, Venezuela) Y ⇔ EC (Iran, Venezuela, Qatar) Mixed outcomes with different models (Nigeria, Saudi Arabia, Indonesia, Kuwait, and UAE)
Halicioglu (2007) [33]	Turkey	1968–2005	ARDL bounds test Granger causality	Y → EC
Tang (2008) [34]	Malaysia	1972–2003	ARDL bounds test Toda and Yamamoto causality test Brown parameter stability test	EC → Y
Abosedra et al., (2009) [35]	Lebanon	1995–2005	Granger causality	EC → Y
Akinlo (2009) [36]	Nigeria	1980–2006	Cointegration Granger causality VECM	EC → Y
Ghosh (2009) [37]	India	1970–2006	ARDL bounds test Cointegration VECM	Y→Electricity supply (short-run)

Table 1. *Cont.*

Author	Country	Period	Methodology	Finding
Acaravci (2010) [38]	Turkey	1968–2005	Cointegration Granger causality VECM	EC → Y
Lorde et al., (2010) [39]	Barbados	1980–2006	Granger causality VECM VAR (vector auto regressive)	EC → Y (short-run) EC ←→ Y (long-run)
Yoo and Kwak (2010) [46]	Argentina Brazil Chile Columbia Ecuador Peru Venezuela	1975–2006	Johansen cointegration Hsiao's Granger causality	EC → Y (Argentina, Brazil, Chile, Columbia, Ecuador) Y ⇔ EC (Venezuela) Y == EC (Peru)
Chandran et al. (2010) [40]	Malaysia	1971–2003	ARDL bounds test Granger causality	EC → Y (short-run) EC → Y (long-run)
Acaravci and Ozturk (2010) [47]	15 transition countries	1990–2006	Pedroni cointegration Granger causality	Y == EC
Apergis and Payne (2011a) [48]	88 countries	1990–2006	Panel cointegration test	Y ⇔ EC (high income and upper-middle-income country panels) EC → Y (short-run, lower-middle-income country panel) Y ⇔ EC (long-run, lower-middle-income country panel) EC → Y (short-run, low income-country panel)
Ozturk and Acravci (2011) [49]	11 Middle East and North Africa (MENA) countries	1971–2006	ARDL bounds test Granger causality	Y → EC (short-run, Israel, Oman) EC → Y (long-run, Egypt and Saudi Arabia) Y == EC (Iran, Jordan, Morocco, Syria)
Bekhet and Othman (2011) [41]	Malaysia	1970–2009	Cointegration Granger causality	EC → Y (long-run)
Shahbaz et al. (2011) [42]	Portugal	1971–2009	ARDL bounds test Granger causality VECM	EC → Y (short-run) Y ⇔ EC (long-run)
Apergis and Payne (2011b) [52]	16 emerging market economies	1990–2007	Panel cointegration Panel Granger causality	Y → REC (short-run) Y ⇔ REC (long-run) Y ⇔ NREC
Apergis and Payne (2012) [53]	6 Central American countries	1990–2007	Panel cointegration test	REC → Y (short-run) Y ⇔ REC (long-run) Y ⇔ NREC
Al-mulali et al. (2014) [54]	18 Latin American countries	1980–2010	Panel cointegration test	Y ⇔ REC (long-run) NREC → Y (short-run) Y ⇔ NREC (long-run)

Table 1. *Cont.*

Author	Country	Period	Methodology	Finding
Halkos and Tzeremes (2014) [55]	36 countries	1990–2011	Nonparametric analysis	Based on Growth hypothesis
Ibrahiem (2015) [51]	Egypt	1980–2011	ARDL bounds testing approach	Y ⇔ REC (long-run)
Kumari and Sharma (2016) [43]	India	1974–2014	Cointegration Granger Causality	Y → EC
Atems and Hotaling (2018) [56]	174 countries	1980–2012	The system generalized method of moments (GMM) approach	Positive relationship between Y, renewable electricity generation and non-renewable electricity generation
Al-Mulali et al. (2018) [50]	Gulf Cooperation Council (GCC) member	1980–2014	Panel cointegration test Panel Granger causality test	Y → EC (short-run) Y ⇔ EC (long-run)
Aydin (2019) [57]	26 OECD countries	1980–2015	Cross-sectional dependence test Panel unit root test Dumitrescu-Hurlin (DH) panel causality test Panel frequency domain causality	Y == EC (DH) Y ⇔ REC, NREC (panel frequency)

Note: Y, EC, REC, NREC mean economic growth, electricity consumption, renewable electricity consumption, and non-renewable electricity consumption, respectively. EC → Y, growth hypothesis; Y → EC, conservation hypothesis; Y ⇔ EC, feedback hypothesis; Y == EC, neutrality hypothesis.

2.3. Revisited Nexus Study

This study tries to investigate the causal relationship between renewable electricity and economic growth. Given what previous studies have referred to as further studies [9,47,56], we "revisited" the nexus study. As mentioned in the previous "Literature Review" section, many studies refer to the existence of a consensus in the nexus field. Nowadays, to try to clarify the related points, several revisited studies are being conducted. Andrew and Bothwell [58] mentioned the limitation of using a bivariate or trivariate model within South Africa. They try to revisit the electricity–growth nexus by using a multivariate model considering the economic aspects of a country like export, employment, and consumer price index. Zortuk and Karacan [59] revisited the energy–growth nexus by selecting countries included in panel data. The ex-Soviet countries located in Central and Eastern Europe and the Caucasus are now in transition into free market economics. Therefore, analysis panel data containing the related countries can clarify the direction of the causal relationship. We also try to revisit the electricity–growth nexus in the same country as the previous study, but we will be using a different methodology and have a different purpose to them.

In this study, we have three distinctions from the previous study. First, the study's purpose is to confirm the renewable electricity–growth nexus by considering the characteristics of renewable energy. This feature is discussed in detail in the next section. Second, to reflect the characteristics that vary depending on the source, we built a model at the renewable source level. The differences in the characteristics of energy sources can affect the investigated findings [56]. There are cases in which previous studies have considered disaggregated level like sources [26,55]; however, only specific sources (steam, hydro, diesel, and gas turbine) were used for data availability and analytical purposes [26]. Halkos and Tzeremes [55] conducted their analysis using wind power, biomass, solar power, and geothermal data. However, the availability of the data used differed from country to country, and a non-parametric technique was applied. The last difference is that generation data is used for the application of the first and second implications mentioned above. The various differences between generation and consumption could affect interpretation in this study, which aimed at reflecting renewable characteristics rather than electricity [40,56]. This study is meaningful in that it analyzes through a revisiting flow in which the implication of the study is made by both the setting of the country and the variables.

3. Data and Methodology

3.1. Renewable–Growth Hypothesis

In this study, we analyze the renewable electricity and economic growth nexus considering renewable manufacturing industries. As mentioned above, the cost structure of renewable electricity is quite different from the conventional thermal power. In the renewable generation sector, much of the cost goes to equipment or facilities, which means a capital expenditure is much higher than an operational expense. On the other hand, the thermal power plants that use fossil fuels have substantial operational costs, although their capital cost is also considerable. Promoting renewable electricity could thus have a positive effect on economic growth through the production of renewable manufacturing industries such as wind turbine and solar panel manufacturing. In other words, renewable electricity can contribute to economic growth through industrial outputs as well as an energy input. We want to call this mechanism the 'renewable–growth' hypothesis in the context of the energy–growth nexus.

To test the renewable–growth hypothesis, we choose a country in which renewable electricity might lead to the development of related industries. We confirm that the renewable–growth nexus in a country includes companies that have developed in the renewable electricity sector. This study attempts to examine the positive relationship between economic growth and renewable electricity demand in such countries based on the market share of renewable manufacturing companies. At the moment, we are analyzing solar PV and wind power, which are expected to grow quickly [3]. We might expect to see a causal relationship by identifying the more disaggregated sectors.

Based on sales volume or revenue, we selected a global renewable energy company in solar [60] and wind [61] power. According to the collected data, we identified the country the company belongs to for analytical purposes. The analysis is conducted on solar and wind power, separately. Tables A1 and A2 show the companies and corresponding countries with the highest sales volume. For the solar PV, we have included the component in the plant and the market share of module companies. Four countries are analyzed for the solar PV: China (including Hong Kong), Canada, the USA, and Korea. A key component of the wind manufacturing industry is the turbine, which accounts for 60% of the total capital expenditure [62]. Thus, the standard for selecting the country included in the wind model is a global wind-turbine company [Table A2]. Wind models include six countries: China, the USA, Denmark, Germany, India, and Spain.

3.2. Data and Estimation Procedure

Consistent with the previous literature, we use real GDP as the dependent variable. Independent variables are electricity generation, gross fixed capital, and labor force. Due to the features of renewables, to transmission, to distribution losses, or even to theft, bias can exist in the investigated result [56]. This feature was also affected by country development level [40,63]. Therefore, we consider electricity generation data. Considering the connectivity to the power grid and intermittent characteristics of renewable energy, the detailed consumption data of each source is not available. To include this, the previous study used aggregate level consumption data. However, this study's purpose is to identify the effects of the nexus depending on the presence of manufacturing companies reflecting the manufacturing feature of each source. Reflecting on the characteristics of the energy source means it must be analyzed at a disaggregated level. Therefore, generation data is used for analysis, and solar PV and wind are configured separately.

We adopt the annual time series data of each country from 1980 to 2017. The data are obtained from the World Bank Development Indicators, World Energy Balances, and US Energy Information Administration and defined as follows: Real GDP (Y) in billion 2010 USD using purchasing power parity, fossil fuel electricity generation (NRE) defined in kilowatt hours, electricity generation from solar PV (RES) defined in kilowatt hours, electricity generation from wind (REW) defined in kilowatt hours, real gross fixed capital formation in current US dollars (K), and total labor force (L) in millions. We convert the unit of real gross fixed capital formation into constant 2010 US dollars using the GDP deflator from WDI. Additionally, all variables are converted to per capita and the natural logarithms are transformed.

3.3. Estimation Strategy

We assume that, due to the characteristics of renewables, renewable electricity generation and economic growth have a relationship. To confirm the causal relationship between them, we must check the stationarity of time series data. If data are not stationary, the estimated model might be a spurious regression and results may lack robustness. Common methods applied to unit root tests are the augmented Dickey–Fuller (ADF) [64], Phillips–Perron (PP) [65], and Kwiatkowski–Phillips–Schmidt–Shin (KPSS) [66]. If the null hypothesis of the ADF and PP tests are rejected, we conclude that time series data has a unit root. The KPSS test is applied to investigate the stationarity, and, if the null hypothesis is rejected, the data may be nonstationary time series data. The KPSS test is more suitable for testing small samples due to the lower lag truncation parameter, and it might complement the limitation of the ADF and PP tests [67]. Therefore, as a tool for cross-checking and for the robustness of results, we conduct ADF, PP, and KPSS tests together.

Before the Granger causality analysis, it is necessary to test for cointegration. There are several methodologies related to cointegration, and the Johansen test [68] is the most common method as it is more generally applicable than the Engle–Granger test [69]. Since this test is common and well known, we provide just a brief overview of this method. Johansen [68] modeled time series as a reduced rank regression, and we can trace test and maximum eigenvalue. The model is given as the following:

$$\Delta Z_t = \omega + \sum_{i=1}^{q-1} \Delta Z_{t-i} + \Pi \Delta Z_{t-1} + \varepsilon_t \tag{1}$$

The Z_t is a vector of p variables consisting of an (n × 1) column, and ω is an (n × 1) vector of constant terms. Γ means coefficient matrices, and Δ is a difference operator. The ε_t follows distribution as $N(0, \Sigma)$. The Π means the coefficient is known as the impact matrix and contains information about the long-run relationships. By employing this method, it is possible to determine the number of the cointegrating vectors of the model.

We can also employ the cointegration test with the autoregressive distributed lag (ARDL) bounds test approach [70]. By using ARDL bounds testing, we can expect to take advantage of the following. First, it is possible to apply such a method irrespective of whether the regressors are I (0) or I (1). Furthermore, compared to the Johansen cointegration techniques, estimating with a smaller sample size is possible [71]. According to Narayan [72], the ARDL bounds test gives a reasonable critical value if the number of samples is between 30 and 80. Furthermore, the ARDL model can be derived in the form of an error correction model. Thi means it is possible to confirm that the long-run and short-run causality is the same as in VECM. In this study, we can establish the ARDL model as the following:

$$\begin{aligned} \Delta GDP_t = \alpha_0 + \sum_{i=1}^{q} \alpha_1 \Delta GDP_{t-i} + \sum_{i=1}^{q} \alpha_2 \Delta NRE_{t-i} + \sum_{i=1}^{q} \alpha_3 \Delta RE_{t-i} + \sum_{i=1}^{q} \alpha_4 \Delta K_{t-i} + \\ \lambda_1 GDP_{t-1} + \lambda_2 NRE_{t-1} + \lambda_3 RE_{t-1} + \lambda_4 K_{t-1} + \mu_t \end{aligned} \tag{2}$$

$$\begin{aligned} \Delta RE_t = \beta_0 + \sum_{i=1}^{q} \beta_1 \Delta RE_{t-i} + \sum_{i=1}^{q} \beta_2 \Delta NRE_{t-i} + \sum_{i=1}^{q} \beta_3 \Delta GDP_{t-i} + \sum_{i=1}^{q} \beta_4 \Delta K_{t-i} + \\ \zeta_1 RE_{t-1} + \zeta_2 NRE_{t-1} + \zeta_3 GDP_{t-1} + \zeta_4 K_{t-1} + \mu_{2t} \end{aligned} \tag{3}$$

where GDP, NRE, RE, and K denote the logarithm form of real GDP, fossil fuel electricity generation, solar PV or wind electricity generation, and gross domestic capital formation, respectively. The parameters α, β are the short-run dynamic coefficient and λ, ζ are the corresponding long-run multipliers of each ARDL model. The μ represents the white noise error term.

To determine the existence of cointegration, we test the lagged value jointly by using the F test. However, as the F statistics from [70] are for several samples, we usually use the critical value from Narayan in the small sample size analysis [72]. The null hypotheses of each model are $H_o: \lambda_1 = \lambda_2 = \lambda_3 = 0$ and $H_o: \zeta_1 = \zeta_2 = \zeta_3 = 0$. If the computed F statistics exceed the upper bound value, the null hypothesis is rejected. However, if the F statistics fall below the lower bound, we can conclude that we cannot reject the no cointegration hypothesis. However, if the value exists between the upper bound and lower bound, the results are inconclusive. Through the cointegration test, if we find the evidence for a long-run relationship between variables, we can conduct the test to check the existence of Granger causality.

According to the results from the cointegration test, there are two cases we must consider. If our variables are not cointegrated, we perform the test as a vector autoregressive (VAR) model in first differenced variable form. If we can confirm the existence of a long-run relationship, we can conduct the model with the error correction term. Thus, the model has a cointegration, and the Granger causality relationships are written as the vector error correction models (VECM) given below:

$$\begin{aligned} \Delta GDP_t = \alpha_0 + \sum_{i=1}^{q} \alpha_{1i} \Delta GDP_{t-i} + \sum_{i=1}^{q} \alpha_{2i} \Delta NRE_{t-i} + \sum_{i=1}^{q} \alpha_{3i} \Delta RE_{t-i} + \sum_{i=1}^{q} \alpha_{4i} \Delta K_{t-i} + \\ \lambda ECT_{t-1} + \mu_{1t} \end{aligned} \tag{4}$$

$$\Delta RE_t = \beta_0 + \sum_{i=1}^{q} \beta_{1i} \Delta RE_{t-i} + \sum_{i=1}^{q} \beta_{2i} \Delta NRE_{t-i} + \sum_{i=1}^{q} \beta_{3i} \Delta GDP_{t-i} + \sum_{i=1}^{q} \beta_{4i} \Delta K_{t-i} + \zeta ECT_{t-1} + \mu_{2t} \quad (5)$$

The null hypothesis of the Granger causality from renewable electricity generation to GDP is $H_o: \alpha_1 = \alpha_2 = \ldots \alpha_q = 0$. To test the short-run causality of renewable electricity to GDP, we impose restrictions on all the lagged renewable electricity generation data using the F test. This is equivalent to the test of lagged first differences of the Granger causality from renewable electricity generation to GDP.

Whether or not they are integrated, the economic variables can be integrated into different orders. In that case, the Wald test will not have an asymptotic chi-square distribution, and VECM cannot be applied for the Granger causality test. Toda and Yamamoto [73] suggest the procedure for solving this problem. According to the standard stationary test, we can determine the order of the variables. Let m be the maximum order of integration, and l be the appropriate maximum lag length in VAR. Then take the preferred VAR model and add the m additional lags of each of the variables. We can test the Granger causality using that model. However, we must test the hypothesis with only the coefficients of the first l lagged values. Rejection of the null hypothesis implies the existence of Granger causality.

4. Empirical Results

4.1. Unit Root Test Results

Tables A3 and A4 present the result of a stationarity test for the solar PV case and the wind power case from ADF, PP, and KPSS test. We use Stata 14.0 for the analysis. The definition of GDP is real GDP, FOG is fossil-fuel electricity generation, RE is renewable electricity generation, and FXC is fixed capital formation. According to the model, RE is divided into solar PV (RES) and wind power (REW). In the process of examining stationarity, the maximum lag length was set to 4 considering the characteristics of the economic variables.

As mentioned above, ADF, PP, and KPSS tests were conducted simultaneously for robustness. If the differenced form does not reject the null hypothesis in more than two tests, the second differenced variable is tested. The first differenced variable is then analyzed based on the statistics considering the trend. Additionally, if we get the result that the first differenced is stationary in at least two tests, we do not write the statistics of the second differenced form in the table. Two or more tests indicate the same order of integration, and we set that value as the integration order of that variable. The results show that most variables in both models are in the form of I (1). Only the GDP variable of Spain in wind power has I (2). Since the order of integration of the variables is mixed, the analysis proceeds with Toda and Yamamoto's procedure.

Therefore, we constructed the VAR model with the variables to find the optimal lag length of the model setting the maximum lag as 4. Lag-order selection is based on Bayesian information criterion (BIC). In each model, the VAR model was constructed according to the optimal time difference obtained in each country, autoregression was checked, and the time difference was adjusted. The order of integration of variables and the optimal lag of the VAR model are summarized in Tables 2 and 3. Table 2 is for the solar PV, and Table 3 is for wind power. To investigate the Granger causality of each country and model, we reconstructed the VAR model with the sum of these two values as the lag length of the new model.

Table 2. Integration order and optimal lag results for solar photovoltaics (PV).

Country	Variables	Order of Integration (m)	Optimal Lag (l)
Canada	GDP	I(1)	1
	FOG	I(1)	
	RES	I(1)	
	FXC	I(1)	
China	GDP	I(1)	3
	FOG	I(1)	
	RES	I(1)	
	FXC	I(1)	
USA	GDP	I(1)	4
	FOG	I(1)	
	RES	I(1)	
	FXC	I(1)	
Korea	GDP	I(1)	3
	FOG	I(1)	
	RES	I(1)	
	FXC	I(1)	

Table 3. Integration order and optimal lag results for wind power.

Country	Variables	Order of Integration (m)	Optimal Lag (p)
China	GDP	I(1)	3
	FOG	I(1)	
	REW	I(1)	
	FXC	I(1)	
USA	GDP	I(1)	5
	FOG	I(1)	
	REW	I(1)	
	FXC	I(1)	
Denmark	GDP	I(1)	2
	FOG	I(1)	
	REW	I(1)	
	FXC	I(1)	
Germany	GDP	I(1)	2
	FOG	I(1)	
	REW	I(1)	
	FXC	I(1)	
India	GDP	I(1)	1
	FOG	I(1)	
	REW	I(1)	
	FXC	I(1)	
Spain	GDP	I(2)	2
	FOG	I(1)	
	REW	I(1)	
	FXC	I(1)	

4.2. Results of the Granger Causality

Tables 4 and 5 summarize the results of the solar PV and wind power, respectively. The country shows that the growth hypothesis presented in the previous nexus study are Canada for the solar PV, and Germany, India, and Spain for wind power. China and the USA were included in both models, satisfying the conservative and feedback hypothesis, respectively. Denmark was the only country with a neutral hypothesis. The renewable–growth relationship is investigated in Canada, USA, and Korea for the solar PV and the USA, Germany, India, and Spain for wind power. China in both models and Denmark in the wind power show different results based on our hypothesis.

Table 4. The results of the Granger causality in solar PV.

Country	Granger Causality	Test Statistics	Hypothesis	
			Conventional	**Renewable–Growth**
Canada	RES → GDP GDP → RES	3.27 * 0.20	Growth	Yes
China	RES → GDP GDP → RES	3.61 8.70 **	Conservative	No
USA	RES → GDP GDP → RES	20.25 *** 25.74 ***	Feedback	Yes
Korea	RES → GDP GDP → RES	18.14 *** 16.48 ***	Feedback	Yes

Note: *, **, and *** denote the rejection of the null hypothesis of no relationship at the 5% and 1% significance level, respectively.

Table 5. The results of the Granger causality wind power.

Country	Granger Causality	Test Statistics	Hypothesis	
			Conventional	**Renewable–Growth**
China	REW → GDP GDP → REW	0.79 23.84 ***	Conservative	No
USA	REW → GDP GDP → REW	18.48 *** 17.12 ***	Feedback	Yes
Denmark	REW → GDP GDP → REW	0.09 0.28	Neutral	No
Germany	REW → GDP GDP → REW	14.00 *** 4.25	Growth	Yes
India	REW → GDP GDP → REW	2.75 * 0.04	Growth	Yes
Spain	REW → GDP GDP → REW	6.26 ** 0.71	Growth	Yes

Note: *, **, and *** denote the rejection of the null hypothesis of no relationship at the 5% and 1% significance level, respectively.

In this study, the standard Granger causality test was also conducted to confirm the reliability of the results. The difference of the standard Granger causality is after the stationarity test, which means identifying the cointegration of the model. The Johansen method was used to confirm the cointegration, and the bounds test was also performed considering the small sample size. If cointegration exists, the VECM model is constructed to confirm the causality of the long run and short run. If the results indicate no cointegration in both tests, a VAR model with a differenced variable must be built, and the short run causality is checked using that model. The lag length of each model is the same as that of Toda and Yamamoto. Tables A5 and A6 summarize the standard Granger causality results. Only China, for the solar PV, shows a conflicting result in the cointegration test. The variables in this model are all I (1), so we follow the bounds test result due to the small sample size. Furthermore, because the lag lengths of Canada for solar PV and India for wind power are both 1, the short-run term disappears when constructing the VECM model. Therefore, both cases were analyzed only in the long-run relationship. However, due to the integration order of the variables, we used and analyzed the results using the Toda and Yamamoto procedure.

5. Discussion

The study aims to investigate the renewable–growth hypothesis of the countries with a renewable manufacturing industry. According to the results, the long-run relationship between renewable electricity generation and economic growth is present in all countries. However, in some countries, the results differ from our hypothesis. The results can be attributed to diverse factors like economic or socio-cultural points existing in different countries [45,47,52,74].

In China, the opposite of the renewable–growth hypothesis was found in both solar PV and wind power. China is the largest producer of both solar and wind components. The total installed solar PV was 175 GW in 2018, while the total for wind power was 185 GW in 2018 [75]. However, China's exports of manufactured goods to other countries are much higher than its domestic use [60,61]. Therefore, the causality test with renewable electricity generation in China may not reflect the positive effect of the renewable electricity industry. China's renewable electricity is also a reason for the ambiguous factor of the renewable–growth relationship. The renewable electricity industry induces economic growth in the indirect sectors, such as the development of the manufacturing sector and employment for facilities and the direct impact of the generation itself. Electricity curtailment due to grid issues is a chronic problem in China [76,77]. The resulting loss of generation has a negative effect on economic growth [60].

Denmark also has a similarity with China. In Denmark, renewable energy accounts for more than 50% of total electricity production [78]. However, the increase in installed wind energy capacity is the smallest among countries with wind power [75]. In the absence of increased domestic facilities, it is difficult to identify the growth hypothesis with given variables. Furthermore, Siemens Gamers has manufacturing facilities worldwide [79]. Vestas' manufacturing facilities are also located in other countries [80]. Thus, even if they satisfy the renewable–growth hypothesis, they may not be revealed under the given variables. In the rest of the target countries, we can examine the renewable–growth hypothesis.

The renewable electricity industry of countries showing a growth hypothesis has been more established in recent years. Germany, which shows the renewable–growth relationship between wind power and economic growth, had the largest wind power capacity in 2017. Germany leads the European Union (EU) in terms of power capacity with 56.1 GW, followed by Spain with 23.2 GW, which is also included in our analysis model. The manufacturing facility of Gamesa, which merged with Danish renewable company Siemens in 2016, still exists in Spain, and this could have a positive effect on the country. According to GWEC [81], one of the leading turbine suppliers for the EU is Siemens Gamesa. While installation numbers have slowed, the total capacity of India is 32.8 GW, taking the fourth position in the world's largest wind markets. Because the share of wind-generated electricity in India's total electricity consumption is still 4.35%, there is still growth potential in India's renewable electricity market [81]. The USA has the highest installed capacity after China among our target countries, both for solar PV and wind power. In 2018, the total installed capacity was 51 GW for solar PV and 94 GW for wind power [75]. In Korea, the installed solar PV capacity is 8 GW, but the number of related companies and employment is increasing due to recent aggressive renewable electricity policies. Canada has also installed a solar PV capacity of 3 GW, and while it is not growing much, it is considered to have high potential as the capacity continues to rise.

Under our hypothesis, the driving force of economic growth is the electricity industry itself, and other industries have induced effects from the increase of renewable generation. We used solar PV generation data and wind power generation data as variables to cover these points. However, these variables do not reflect the growth effect of the renewable manufacturing industry effectively in some countries. Development of relevant industries can lead to the growth of domestic products usage. So we set renewable electricity data as a variable in our model. This is a limitation of the study in that it does not consider the characteristics of trade. In the same line, the diverse factors that are inherent in countries need to be considered. The various political, economic, and socio-cultural factors could cause a bias in the nexus study. Therefore, further research to secure the renewable–growth hypothesis is necessary. Developing variables to consider the export-focused characteristic and renewable energy policy of each country could also be the next step of the renewable–growth hypothesis. Furthermore, the existence of renewable growth may not be revealed in the results due to bias arising from the small sample size. It is necessary to overcome this limitation in the future with continuous research on specific energy sources. A country's characteristics may vary and be embodied in the results, so it also becomes the motivation for additional research. Lastly, our study is the first to present the renewable–growth hypothesis. However, it must be noted that while we use an analysis strategy by using Granger causality, it is unknown whether the relationship is positive or negative [82]. A more diversified approach could make it clear whether the hypothesis is correct or not.

6. Conclusions

The increasing concerns about the climate crisis cause trends such as energy transition from fossil fuels to renewable energy. According to the change in the power mix, the renewable electricity industry is affected both directly and indirectly. The difference between conventional electricity and renewable electricity sources lies in the weight of manufacturing-related parts. This is the case with solar PV and wind power, both comprising the world's highest growth in renewable electricity installation. Due to such characteristics, the increase in renewable energy generation has the additional effect of not only leading to advantages in the generation industry but also the development of related industries and increase in employment. As this will have a positive effect on economic growth, we have thus formulated the renewable–growth hypothesis, which is one step further from the growth hypothesis of the existing nexus studies.

In this study, we tried to investigate the relationship between renewable electricity and economic growth. We constructed and analyzed more disaggregated models like solar PV and wind power. Additionally, we established the target group based on global companies in manufacturing. It was expected that the renewable–growth relationship would be represented more accurately in those countries. The variables within the model are real GDP, fossil fuel electricity generation, renewable electricity generation, and fixed capital formation. Renewable electricity generation means the solar PV data for solar PV and wind power data in wind power. Because our purpose is to confirm the renewable–growth hypothesis, we used electricity generation as a variable, considering the difference between generation and consumption data.

The analysis showed that the renewable–growth hypothesis was satisfied except only China for solar PV and China and Denmark for wind power. These results are due to the characteristics of the country's power and power-related manufacturing industries. We can thus conclude that national and industry characteristics can influence the results of the analysis. Furthermore, we can provide the direction for further studies. First, renewable electricity time series data has a relatively small sample size. Therefore, if data is acquired over time, it is necessary to analyze a larger sample size. Doing this would determine the renewable–growth relationship more accurately. Second, considering additional variables to reflect the characteristics of industry or country would be necessary. However, as we can see from the results of other countries, the parameters were appropriate for verifying the hypothesis. Thus, while considering the general case, further research is necessary to reflect the characteristics of each country. The study's main contributions are its presentation of a new perspective in the form of the renewable–growth hypothesis and the establishment and analysis of a target group that reflects the characteristics of the renewable electricity industry.

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Appendix A

Table A1. The highest production company in solar PV (module).

Rank	Company	Country	Production [MW]
1	Jinko Solar	China	9000
2	JA Solar	China	8500
3	Canadian Solar	Canada	8310
4	Hanwha Q CELLS	Korea	8000
5	Trina Solar Ltd.	China	8000
6	Risen	China	6600
7	GCL System	China	5400
8	Talesun	China	4500
9	Suntech/Shunfeng	China	3300
10	Znshine Solar	China	3200
11	Seraphim	China	3000
12	Chint/Astronergy	China	2500
13	First Solar	USA	2200
14	Eging	China	2000
15	BYD	China	1700

Table A2. The market share of global wind power companies.

Rank	Company	Country	Market Share (%, 2014)
1	Vestas	Denmark	16%
2	Siemens Gamesa	Denmark	15%
3	Goldwind	China	12%
4	GE Wind	USA	10%
5	Enercon	Germany	7%
6	Nordex	Germany	6%
7	Envision	China	6%
8	Senvion	Germany (India)	3%
9	Suzlon	India	3%
10	Guodian UP	China	3%
11	Ming Yang	China	2%

Appendix B

Table A3. Unit root test results for solar PV.

Country	Variables		Test Statistics		
			ADF	PP	KPSS
Canada	GDP	Level	−2.144	−6.105	0.225 ***
		First difference	−4.556 ***	−26.242 ***	0.116
	FOG	Level	−1.233	−3.816	0.416 ***
		First difference	−6.374 ***	−40.340 ***	0.0413
	RES	Level	−2.427	−10.865	0.113
		First difference	−3.013 **	−15.118 **	0.0943
	FXC	Level	−2.565	−7.935	0.25 ***
		First difference	−5.095 ***	−31.560 ***	0.0992

Table A3. *Cont.*

Country	Variables		Test Statistics		
			ADF	PP	KPSS
China	GDP	Level	−2.371	−10.118	0.183 **
		First difference	−3.094 **	−15.071 **	0.0984
	FOG	Level	−1.804	−8.698	0.2 **
		First difference	−3.546 **	−17.539 **	0.187 **
	RES	Level	−0.372	−0.427	0.7 ***
		First difference [1]	−4.122 **	−24.522 ***	0.116
	FXC	Level	−1.750	−6.024	0.413 ***
		First difference	−3.875 ***	−17.560 **	0.128 ′
USA	GDP	Level	−0.485	−0.967	0.301 ***
		First difference	−5.216 ***	−30.371 ***	0.244 ***[2]
	FOG	Level	1.072	2.428	0.343 ***
		First difference	−6.544 ***	−41.387 ***	0.158 *[2]
	RES	Level	−2.923	−7.352	0.266 ***
		First difference	−5.637 ***	−35.112 ***	0.0927
	FXC	Level	−2.716	−11.397	0.142 ′
		First difference	−5.800 ***	−34.972 ***	0.0615
Korea	GDP	Level	−3.063	−8.906	0.126 ′
		First difference	−2.654 *	−13.941 **	0.293 ***[2]
	FOG	Level	−1.362	−5.247	0.113
		First difference	−2.902 *	−52.064 ***	0.0957
	RES	Level	−2.557	−11.407	0.111
		First difference	−2.963 *	−46.013 ***	0.112
	FXC	Level	−2.222	−8.004	0.284 ***
		First difference	−5.671 ***	−34.438 ***	0.06

Note: *, **, and *** indicate the level of significance at 10%, 5%, and 1% for ADF, PP. ′, *, **, and *** indicate the level of significance at 10%, 5%, 2.5%, and 1% for KPSS. [1] first difference form using trend when testing ADF and PP. [2] the result of second difference form is stationary.

Table A4. Unit root test results for wind power.

Country	Variables		Test Statistics		
			ADF	PP	KPSS
China	GDP	Level	−2.371	−10.118	0.183 **
		First difference	−3.094 **	−15.071 **	0.0865
	FOG	Level	−1.804	−8.698	0.164 *
		First difference	−3.546 **	−17.539 **	0.158 *[2]
	REW	Level	−2.863	−10.116	0.0846
		First difference	−4.715 ***	−28.629 ***	0.0773
	FXC	Level	−1.750	−6.024	0.413 ***
		First difference	−3.875 ***	−17.560 **	0.128 ′[2]
USA	GDP	Level	−0.485	−0.967	0.301 ***
		First difference	−5.216 ***	−30.371 ***	0.244 ***[2]
	FOG	Level	1.072	2.428	0.343 ***
		First difference	−6.544 ***	−41.387 ***	0.158 *[2]
	REW	Level	−2.515	−10.241	0.305 ***
		First difference [1]	−7.100 ***	−43.660 ***	0.033
	FXC	Level	−2.716	−11.397	0.142 ′
		First difference	−5.800 ***	−34.972 ***	0.0615

Table A4. *Cont.*

Country	Variables		Test Statistics		
			ADF	**PP**	**KPSS**
Denmark	GDP	Level	−1.684	−3.320	0.414 ***
		First difference	−4.619 ***	−27.620 ***	0.0744
	FOG	Level	−0.391	−1.660	0.426 ***
		First difference	−8.083 ***	−48.551 ***	0.0307
	REW	Level	−2.446	−1.864	0.448 ***
		First difference	−4.422 ***	−24.953 ***	0.0876
	FXC	Level	−2.696	−13.698	0.175 *
		First difference	−4.836 ***	−28.317 ***	0.102
Germany	GDP	Level	−1.291	−2.180	0.444 ***
		First difference	−4.301 ***	−25.521 ***	0.114
	FOG	Level	−1.094	−6.726	0.225 ***
		First difference	−6.980 ***	−44.514 ***	0.0939
	REW	Level	−0.777	−0.912	0.459 ***
		First difference	−2.665 *	−12.125 *	0.331 ***[2]
	FXC	Level	−3.843 **	−11.353	0.128 ′
		First difference	−2.662 *	−30.106 ***	0.0918
India	GDP	Level	−1.422	−2.319	0.454 ***
		First difference	−3.879 ***	−22.200 ***	0.0682
	FOG	Level	−2.775	−3.588	0.411 ***
		First difference	−4.405 ***	−26.979 ***	0.167 *[2]
	REW	Level	−1.771	−5.858	0.318 ***
		First difference [1]	−5.555 ***	−34.473 ***	0.162 *[2]
	FXC	Level	−1.843	−6.219	0.342 ***
		First difference	−6.157 ***	−38.722 ***	0.0848
Spain	GDP	Level	−2.854	−5.346	0.239 ***
		First difference	−2.704 [1]	−15.080 **	0.225 ***
		Second difference	−8.087 ***	−45.537 ***	0.0283
	FOG	Level	−1.146	−7.526	0.173 *
		First difference	−5.891 ***	−44.595 ***	0.0633
	REW	Level	−0.946	−3.469	0.394 ***
		First difference [1]	−4.827 ***	−29.612 ***	0.328 ***[2]
	FXC	Level	−2.425	−7.233	0.166 *
		First difference	−3.404 **	−22.619 ***	0.117

Note: *, **, and *** indicate the level of significance at 10%, 5%, and 1% for ADF, PP. ′, *, **, and *** indicate the level of significance at 10%, 5%, 2.5%, and 1% for KPSS. [1] first difference form using trend when testing ADF and PP. [2]: the result of second difference form is stationary.

Appendix C

Table A5. The results from the standard Granger causality test in solar PV.

Country	Cointegration		Granger Causality	
	Johansen	**Bounds Test**	**Short-Run**	**Long-Run**
Canada	Rank 1	6.388 ***	-[1]	RES → Y ***
China	Rank 1	1.935	RES → Y **	-[2]
USA	Rank 1	4.867 *	No causality	RES → Y *
Korea	Rank 1	10.649 ***	Y → RES ***	RES → Y *** Y → RES ***

Note: ′, *, **, and *** indicate the level of significance at 10%, 5%, 2.5%, and 1% for bound-testing. *, **, and *** indicate the level of significance at 10%, 5%, and 1% for Granger causality. [1] the lag of this model is 1, so we can investigate the long-run relationship result only. [2] according to the bounds test result, we investigate the short-run relationship using only VAR.

Table A6. The results from the standard Granger causality test in wind power.

Country	Cointegration		Granger Causality	
	Johansen	**Bounds Test**	**Short-Run**	**Long-Run**
China	Rank 1	5.951 ***	No causality	No causality
USA	Rank 1	4.737 ***	Y → REW **	No causality
Denmark	Rank 2	4.041 ′	No causality	REW → Y ***
Germany	Rank 1	8.590 ***	REW → Y * Y → REW *	REW → Y ***
India	Rank 2	5.888 ***	-[1]	REW → Y **
Spain	Rank 3	16.836 ***[3]	REW → Y **	Y → REW *

Note: ′, *, **, and *** indicate the level of significance at 10%, 5%, 2.5%, and 1% for Bound-testing. *, **, and *** indicate the level of significance at 10%, 5%, and 1% for Granger causality. [1] the lag of this model is 1, so we can investigate the long-run relationship result only. [2] this model does not have cointegration, so we can investigate the short-run relationship only. [3] while this model includes the I (2) variable, we applied the bounds test for reference.

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