Hindawi
International Journal of Energy Research
Volume 2023, Article ID 1683231, 14 pages
https://doi.org/10.1155/2023/1683231

WILEY | Hindawi

*Research Article*

# Analyzing Nexus between Economic Complexity, Renewable Energy, and Environmental Quality in Japan: A New Evidence from QARDL Approach

**Muhammad Haroon Shah ,[1] Huang De Chun,[1] Yichu Wang ,[2] Irfan Ullah ,[3] Syed Tauseef Hassan,[4] and Zeeshan Fareed [5]**

[1]*Business School, Hohai University, Nanjing 210098, China*
[2]*School of Oriental and African Studies (SOAS), University of London, UK*
[3]*Reading Academy, Nanjing University of Information Science and Technology, Nanjing 210044, China*
[4]*School of Economics and Management, Anhui Polytechnic University WuHu 241000, China*
[5]*Centre for Transdisciplinary Development Studies, University of Trás-os-Montes and Alto Douro, Vila Real, Portugal*

Correspondence should be addressed to Yichu Wang; wangyichu1993@163.com

Received 9 February 2023; Revised 23 July 2023; Accepted 1 August 2023; Published 22 August 2023

Academic Editor: Mucahit Aydin



The economic complexity index is an effective dimensionality reduction tool that is applied to forecast and predict future economic growth, income, and environmental quality. Renewable energy plays an important role in mitigation of carbon dioxide emissions. This study explores the nexus between economic complexity, renewable energy, FDI, trade, and environmental quality in Japan for the period 1970Q1-2019Q4. We use carbon dioxide ($CO_2$) emissions as dependent variable while economic complexity index (ECI), foreign direct investment (FDI) inflow, renewable energy (RNE), and trade as explanatory variables. This study applies a quantile autoaggressive approach for analysis; the result of this study suggests a long-run implication of the ECI, FDI, GDP, RNE, and trade for the $CO_2$ emissions. While only RNE and trade show mixed results in the short run, the rest of the variables do not have short-run implications. This implies that emissions mostly result in the industrial production activities only in the long run and in some quantiles only in the short run. The Japanese government may adopt different measures to reduce the $CO_2$ emissions in the country, such as carbon tax and tax exemption on renewable energy investment. Furthermore, the government may adopt the renewal energy in production, which could achieve sustainable development goal.

## 1. Introduction

Environmental pollution, climate change, and $CO_2$ emissions are major risk that humanity faces over the decades. These are urgent issues for the world, and it needs serious attention. Rapid development and growth across the globe have a greater impact on environmental pollution. The increase in greenhouse emissions leads to global warming which is the main threat to humanity. The main reason for global warming is environmental degradation which is reported by United Nations [1]. According to OECD (Organization for Economic Co-operation and Development) by 2050, greenhouse emission is projected to increase up to 50% due to growth in 70% energy-related $CO_2$ emission. Furthermore, the atmospheric concentration is projected to increase up to 685 parts per million $CO_2$ emissions. Environmental pollution is defined as the destruction of ecosystem, waning the environment by resource depletion such as water, air, and soil; and these are measured by $CO_2$ emissions in most studies. The increase in $CO_2$ emissions has greater impact on health-related issues; also, global warming is the main cause of natural disaster [2]. According to Can et al. [3], due to rise in global warming, the chance of natural disaster is more such as ozone depletion, sea level rising, and

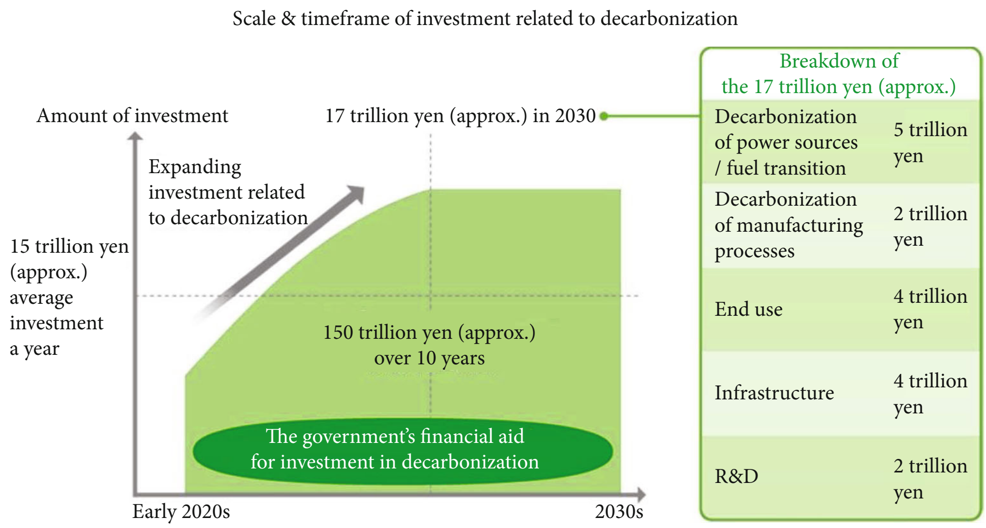


Figure 1: Japan clean energy strategy. Source: clean energy strategy to achieve carbon neutrality by 2050.

heavy storm. With the increase in emissions, many health-related issues also raise like premature death, lung tissue raptures, cardiac diseases, and bronchitis.

Keen focus on environmental issues leads to imitation on international level by many countries such as Kyoto Protocol and the Paris Accord to combat against the climate change and greenhouse gases. In December 2015, the landmarks were set at Paris Accord to keep the temperature level increase below 2°C above the preindustrialization and make sure to maintain it at 1.5°C [4]. The Kyoto Protocol and the Paris climate agreement have given countries important obligations in the fight against climate change. In the Kyoto Protocol, countries are divided into Annex 1 and Annex 2 according to their level of development. Annex 2 is a subset of Annex 1. Japan is among the Annex 2 countries with the highest liability. Annex 2 countries have serious responsibilities on issues such as technology transfer and reducing greenhouse gases. In addition, these countries should use green taxes as a fiscal policy tool. Japan is the fourth leading importer in terms of coal and petroleum and leading in liquefied natural gases. According to the World Bank [5], Japan is the 3$^{rd}$ biggest economy with a total GDP of US $4.872 trillion in 2018. Also, in greenhouse gas emission, Japan is on the 7$^{th}$ largest in the world. In 2011, due to Fukushima nuclear crisis, its decarbonization efforts were postponed. Japan's future plan is to install large number of coal power plants in order to cut the greenhouse gases by 26% below the 2013 levels by the end of 2030 as shown in Figure 1 [6]. Japanese government promotes 3R initiative to reduce pollution which encourages citizen and business to pay attention to impotence of reducing, reusing, and recycling waste. The recycling rate increased over 80% while recycling rate of Japan total waste over the past decades remained low up to 20% [7].

The complexity index was originally proposed by Hidalgo and Hausmann [8] and Hausmann et al. [9]. It is based on the method to analyze the structural properties of the mutual trade network of the world to explain the income per capita gap across the countries. They apply this process for useful explanation of the country performance by measuring complexity indices of the countries across the globe and their export products from mutual trade between countries. According to Hausmann et al. [10], "economic complexity reflects the amount of knowledge that is embedded in the productive structure of an economy." The ECI (economic complexity index) is used for the prediction and explanation of future growth, income, and GHG emissions. Japan in 2019 ranks 4$^{th}$ in total exports while 5$^{th}$ in terms of imports across the globe; with respect to income per capita, its economy ranks 27$^{th}$ in the world. Japan makes significant contribution in the economic growth and reduces the income inequality and greenhouse gas emissions. Whereas its economy is ranked number 1 by ECI, Japan over the past two decades remains on top in economic complexity index.

In the prevailing literature, most of the scholars focus on the $CO_2$ emission determinants which are considered as threats by the United Nations to the world. For example, many studies explored the effect of renewable energy [11–14], foreign direct investment inflow [15–17], economic complexity [18–20], trade [21–23], and income [24, 25]. In the field of environmental economics, many scientists investigated the various impacts of independent variables on $CO_2$ emission. They used different independent variables such as foreign direct investment, economic growth, trade openness, urbanizations, tourism, and financial development to check their impact on $CO_2$ emissions.

In the era of technology, international trade across the globe increases tremendously, and that is linked with income, growth, $CO_2$ emissions, and energy consumptions. The higher the trade, the higher will be the production; that means, more consumption of energy and more trade lead to more greenhouse emissions. Looking into the facts, trade is one of the important variables that have greater impact on income, energy, and $CO_2$ emissions [13]. In literature, there is a well-established link between renewable energy and $CO_2$ emission, and it is consistent with decreasing effect of renewable energy and consumption over $CO_2$ emissions [14].

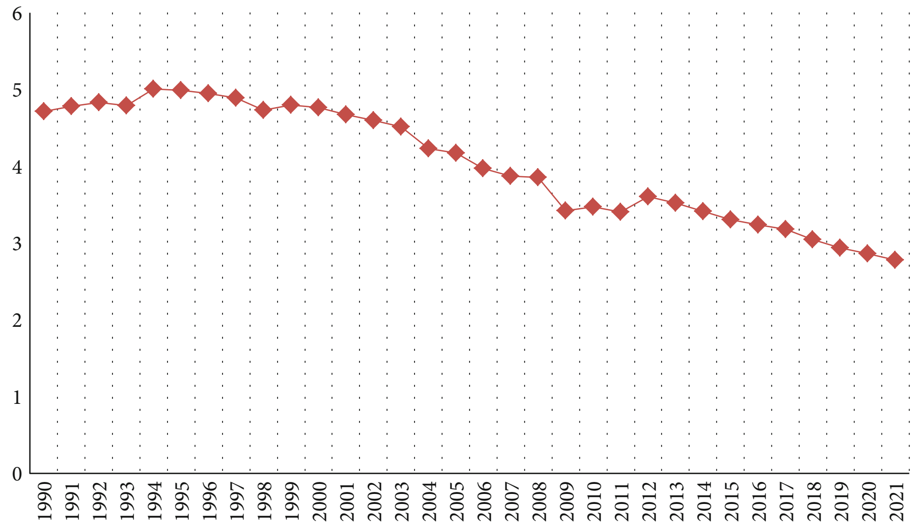


Figure 2: Japan % contribution towards global $CO_2$ emissions. Source: BP Statistical Review of World Energy [28].

According to Shahzad et al. [26], the expected renewable energy will reach 21% by 2030 of total energy consumption. There is a significant and positive effect of FDI inflow in $CO_2$ emissions but relatively small [27]. After the 2011 Fukushima nuclear disaster, Japan starts to use fossil fuels, and the Japanese government took some serious measures to reduce $CO_2$ and reduce greenhouse gas emission below 2013 level by 2030 [28]. Figure 2 shows that there is downward trend in Japan contribution to global $CO_2$ emission; as in 2012, it was 3.67% while in 2021, it reduced to 2.77% of global $CO_2$ [28]. Azhgaliyeva et al. [29] and Abu-Rumman et al. [30] found that tax exemption or reduction on renewable energy investments improves renewable energy production. Japan may boost the renewable energy production by following the tax incentive strategies. Despite the mixed and unclear results in previous studies, further research is required to investigate the linkage of economic complexity, income, FDI inflow, and renewable energy.

In this research, we aim to analyze the relationship between $CO_2$ emission and economic complexity, renewable energy, income, trade, and foreign direct investment inflow in Japan for the period of 1965-2019. This study is aimed at offering answers to the following questions via more accurate and extensive empirical studies: Does ECI truly matter for environmental quality? How to deal with environmental issues by using ECI? To achieve sustainable development goal, these questions are very crucial to answer. The results of this study would further assist policymakers in understanding weather economic complexity has an impact on $CO_2$ emissions, by applying innovative econometric approach to examine the relationship between ECI, renewable energy, FDI inflow, and trade for Japan. Japan plays a substantial role in fostering economic growth, mitigating income inequality, and curbing greenhouse gas emissions. According to the economic complexity index (ECI), Japan has achieved the top ranking in ECI. Japan has consistently maintained its position at the forefront of the economic complexity index over the course of the last two decades. Therefore, it is essential to analyze the relationship between ECI, environmental quality, and renewable energy.

Our study enhances existing literature in three significant ways. Firstly, our research diverges from prior studies by utilizing the economic complexity index, renewable energy, income, trade, and FDI inflow to examine potential variations in $CO_2$ emissions for Japan. We chose Japan due to its consistent ranking as number one in the economic complexity index (ECI) over the past two decades. Secondly, previous literature such as Ikram et al. [31] investigated the ecological footprint and its impact on Japan's economic complexity index. Their findings suggest that the quantile Granger causality shows bidirectional causality between economic development, economic complexity, and ecological footprint in low and high quantiles. In addition, in the short and long terms, QARDL shows asymmetric positive relationship between economic growth and the environment. Adedoyin et al. [32] also examine the case of Japan for economic complexity with renewable and nonrenewable energy, and they concluded that renewable energy and $CO_2$ emissions have significant positive relationship. Thirdly, numerous authors have previously explored and examined the impact of renewable energy, income, FDI, and trade on $CO_2$ emissions using various econometric techniques such as ARDL, nonlinear ARDL, fully modified OLS (FMOLS), and dynamic DOLS. Our study adopts the QARDL method, which significantly differs from earlier methods in several aspects. Firstly, the QARDL approach offers a more appropriate econometric framework for examining the relationships under investigation and enables testing the consistency of these relationships across quantiles. Although the linear ARDL model shares some similarities with the QARDL model, the latter holds the advantage of better identifying potential irregularities on how environmental quality responds to the influence of the economic complexity index, foreign direct investment inflow, GDP, trade, and renewable energy under various conditions.

The rest of the paper explains this as the second part of the study provides some overview of the literature, and the data and methodology are explained in the third part, whereas the fourth part of the study is about results and discussion of the analysis. The fifth and final part is about the conclusion with policy recommendations and limitations.

## 2. Literature Review

There are many papers in the literature that try to explore the linkage between $CO_2$ emissions, economic growth, renewable energy, FDI, and trade across the globe using different econometric techniques, but their results are inconclusive. However, the focus of this study is to investigate and review the relevant papers related to the desired variables.

*2.1. Economic Complexity Index (ECI): Environmental Quality.* There is a significant relationship that exists between environment and complexity index. Mealy and Teytelboym [33] and Romero and Gramkow [20] provide evidence that economic complexity index significantly reduces $CO_2$ emissions as well as improves environmental performance too. The association between environment and economic complexity started from the evolution of all economic structure factors; such that at the beginning, economic complexity index and production play the main role in affecting the environment, but later, with the advancement of technology in production, it is more environmentally friendly. Therefore, economic complexity reduces energy consumption which leads to less $CO_2$ emissions [34]. Martins et al. [35] investigate the top 7 economic complexity index countries and found that ECI increases $CO_2$ emission. Abbasi et al. [36] and Ahmed et al. [37] suggested that ECI and environmental quality show positive associations for various countries. Similarly, the findings of Swart and Brinkmann [38] and Neagu [19] also support that ECI improves the environmental quality both in Brazil and the European Union economies, respectively. Doğan et al. [18] indicate the effect of economic complexity as a knowledge base production on $CO_2$ emissions for 55 countries for a time span of 45 years. They stated that economic complexity has had a significant impact on $CO_2$ emissions. Furthermore, economic complexity has different effects with respect to their income basis.

*2.2. Foreign Direct Investment and Trade: Environmental Quality.* The role of foreign direct investment (FDI) inflows affects economic growth and environmental pollution. According to Naughton [39], FDI inflow in countries with weak environmental regulations increases environmental pollution in the host country. Similarly, Rezza's [40] findings also suggest that FDI inflows increase the output of the country, but it also leads to an increase in environmental pollution. On the contrary, the impact of FDI on $CO_2$ emission for major developed countries in the perspective debate in the Post-Paris Agreement (COP21) on curbing $CO_2$ emissions was investigated by Nguyen et al. [41], and they found that FDI has a negative and weak effect on $CO_2$ emissions. Paramati et al. [42] study the effect of FDI, income per capita, and green technology on $CO_2$ emissions for OCED countries and found that FDI inflow and trade openness significantly reduce the $CO_2$ emissions. There are mixed findings about the role of FDI in literature. Some studies found a positive impact of FDI on environmental pollution such as Al-Mulali and Tang [43] and Jiang et al. [44]. On the other hand, findings of some studies are that FDI flows increase $CO_2$ emission, e.g., Tang and Tan [45], Abdouli and Hammami [46], and Nasir et al. [47], whereas some scholars found that there are insignificant and inconclusive results between both variables, e.g., Lee [48] and Zhu et al. [49]. In conclusion, the contradiction of empirical findings mainly arises due to the use of different factors such as trade and income in the model, and it depends upon the channel to be investigated and the nexus between both variables.

*2.3. Income: Environmental Quality.* $CO_2$ emission has a rapid increase in low- and middle-income countries due to economic development; for example, China is on the top in carbon-emitting countries followed by the US, India, Russia, Brazil, Japan, and Canada because of high energy demand and growing income [50]. Environmental Kuznets curve (EKC) shows that there is linkage between economic developments and $CO_2$ emission at certain level of income, but with renewable energy and efficient technology, the $CO_2$ emission can be decreased at specified level. A casual association between carbon dioxide, trade openness, and income was investigated for the European Union (EU) member and found that there is evidence of inverted U-shaped link between environment an income [24]. In empirical studies, there are various types of relationship among $CO_2$ emissions and income. Many scholars found that there is unidirectional relationship between them such as Uddin et al. [51], Hossain [52], and Shahbaz et al. [23]. They found unidirectional link for $CO_2$ emissions and income for Sri Lanka, Japan, and Indonesia, respectively, while some researchers found that economic growth and energy consumption lead to increase in $CO_2$ emissions, such as Balsalobre-Lorente et al. [53] and Ahmed et al. [54]. Lee and Lee [55] examined the stationary effect of income and $CO_2$ emission for 109 countries and divided into seven regions over the period of 1971-2003. They found that $CO_2$ emissions and income show mixture of I(0) and I(1) processes, and furthermore, due to different order of integration between $CO_2$ and income, results have critical implications for modeling both variables. Aydin et al. [56] examined the multifactor productivity, research and development expenditure, and renewable energy consumption on ecological footprint in G7 countries and concluded that the implementation of policies targeting the expansion of renewable energy sources and the allocation of resources towards research and development in G7 nations will yield favorable outcomes for the environment. Degirmenci and Aydin [57] examine the effects of environmental taxes on environmental pollution and unemployment for selected African countries and concluded that environmental tax improves pollution.

*2.4. Renewable Energy: Environmental Quality.* Renewable energy has great importance due to its less and limited impact on environment and atmosphere with respect to fossil and other nonrenewable energy sources [26, 58]. According to Wang et al. [14], the top ten renewable generating countries significantly reduce $CO_2$ emissions in the long run. According to Apergis et al. [59] for sub-Saharan African countries, renewable energy mitigates $CO_2$ emission in the long run, but in the short run, it shows bidirectional causality. Kahia et al. [60] and Raza and Shah [61] suggested that renewable energy consumption has great contribution in reduction in $CO_2$ emission in MENA and G7 countries. A bunch of literature on the dynamic linkage between renewable energy consumption, growth, and $CO_2$ emissions is mixed. Rahman and Vu [13] studied the relationship between renewable energy consumptions and $CO_2$ emission for Australia and Canada and found that renewable energy significantly decreases $CO_2$ emission. There is casual relationship between energy consumption and $CO_2$ emissions in the long run for India [62]. $CO_2$ emissions have impact on renewable energy for 12 MENA countries, there is unidirectional causality in the long run, and $CO_2$ emission has significant effect on energy consumptions [63]. There is casual relationship between the dynamic effect of renewable energy consumption and environmental degradation for Tunisia. Bekun [64] and Quito et al. [65] examine the relationship between renewable energy and $CO_2$ emissions and suggest a negative relationship between $CO_2$ emissions and renewable energy. The impact of economic complexity and renewable and nonrenewable energy consumption using environmental Kuznets curve (EKC) hypothesis for the USA was examined by Pata [66]. The author found that renewable energy plays dominant role in reducing $CO_2$ emissions and environmental pollution. Bekun et al. [67] also suggest a negative relationship between renewable energy and $CO_2$ emissions. Overall, renewable energy is one of the main sources of reducing $CO_2$ emissions.

## 3. Methodology

To examine the relationship between economic complexity index (ECI), trade, FDI inflow, renewable energy, and environmental quality, QARDL (quantile autoregressive distributed lag) was recently developed and introduced by Cho et al. [68].

The empirical analysis was conducted using the quantile autoregressive distributed lag method. This methodology explains the potential asymmetry in the relationship between one variable and another variable across various quantiles. The QARDL methodology is favored due to its ability to provide detailed information for different quantiles, which is lacking in conventional OLS and linear ARDL techniques that are based on conditional mean. As a result, the quantile autoregressive distributed lag (QARDL) model yields diverse outcomes across these quantiles.

The QARDL model is capable to analyze the effect of long-term equilibrium of economic complexity index, FDI inflow, renewable energy, and export basket on environmental quality of Japan using different quantiles. We also use the Wald test, which verifies the consistency of integrating coefficients across quantiles, to analyze the time-varying integration between the variables [69]. Here is how the standard ARDL model for analyzing cointegration between variables is set up:

$$\begin{aligned} CO_{2,t} = \alpha + \sum_{i=1}^{p} \phi_i CO_{2t-i} + \sum_{i=0}^{q1} \omega_i ECI_{t-i} + \sum_{i=0}^{q2} \lambda_i FDI_{t-i} \\ + \sum_{i=0}^{q3} \theta_i GDP_{t-i} + \sum_{i=0}^{q4} \vartheta_t Trade_{t-i} + \sum_{i=0}^{q5} \mu_t RNE_{t-i} + \epsilon_t. \end{aligned} \tag{1}$$

The error term $\epsilon_t$ is shown as $CO_{2t} - E[CO_{2,t}/F_{t-1}]$. The $\sigma-$ field is the smallest $F_{t-1}$ generated by $\{ECI_t, FDI_t, GDP_t, Trade_t, RNE_t, CO_{2,t-1}, FDI_{t-i}, GDP_{t-i}, Trade_{t-i}, RNE_{t-i} \cdots .\}$. To select the optimum log orders, we used the Schwarz information criterion (SIC) in the equation, that is, $p$, $q1$, $q2$, and $q3$. Equation (1) shows that $ECI_t$, $FDI_t$, $GDP_t$, $Trade_t$, and $RNE_t$ are the log of economic complexity index, foreign direct investment inflow, GDP per capita, trade percentage of GDP, and renewable energy of Japan, respectively, whereas $CO_{2,t}$ shows the logarithm of environmental quality for Japan. The extended and rewise form of equation (1) by Cho et al. [68] to the basic QARDL $(p, q)$ model is shown as

$$\begin{aligned} QCO_{2,t} = \alpha(\tau) + \sum_{i=1}^{p} \phi_i(\tau) CO_{2t-i} + \sum_{i=0}^{q1} \omega_i(\tau) ECI_{t-i} \\ + \sum_{i=0}^{q2} \lambda_i(\tau) FDI_{t-i} + \sum_{i=0}^{q3} \theta_i(\tau) GDP_{t-i} \\ + \sum_{i=1}^{q4} \vartheta_i(\tau) Trade_{t-i} + \sum_{i=1}^{q4} \mu_i(\tau) RNE_{t-i} + \epsilon_t(\tau), \end{aligned} \tag{2}$$

where $\epsilon_t(\tau) = CO_{2,t} - QCO_{2,t}(\tau/F_{t-1})$ and $QCO_{2,t}(\tau/F_{-}(t-1))$ is defined as the $\tau^{th}$ quantile of $CO_{2,t}$ conditional on the information set $F_{t-1}$ [70]. To analyze the QARDL, equation (2) can be rearranged as follows:

$$\begin{aligned} Q_{CO_{2,t}} = \alpha(\tau) + \sum_{i=1}^{q1-1} \delta_{ECI_i}(\tau) \Delta ECI_{t-1} + \gamma_{ECI}(\tau) ECI_t \\ + \sum_{i=1}^{q2-1} \delta_{FDI_i}(\tau) \Delta FDI_{t-i} + \gamma_{FDI}(\tau) FDI_t \\ + \sum_{i=0}^{q3-1} \delta_{GDP}(\tau) \Delta GDP_{t-1} + \gamma_{GDP}(\tau) GDP_t \\ + \sum_{i=0}^{q4-1} \delta_{Trade}(\tau) \Delta Trade_{t-1} + \gamma_{Trade}(\tau) Trade_t \\ + \sum_{i=0}^{q3-1} \delta_{RNE}(\tau) \Delta RNE_{t-1} + \gamma_{RNE}(\tau) RNE_t + \epsilon_t(\tau), \end{aligned} \tag{3}$$

where $(\tau)=\sum_{i=0}^{q1}\omega_i(\tau)$, $\delta_{\mathrm{ECI}_t}(\tau)=-\sum_{j=i+1}^{qi}\omega_i(\tau)$, $\gamma_{\mathrm{FDI}}(\tau)=\sum_{i=0}^{q1}\lambda_i(\tau)$, $\delta_{\mathrm{FDI}_t}(\tau)=-\sum_{j=i+1}^{qi}\lambda_i(\tau)$, $\gamma_{\mathrm{GDP}}(\tau)=\sum_{i=0}^{q1}\theta_i(\tau)$, $\delta_{\mathrm{GDP}_t}(\tau)=-\sum_{j=i+1}^{qi}\theta_i(\tau)$, $\gamma_{\mathrm{Trade}}(\tau)=\sum_{i=0}^{q1}\theta_i(\tau)$, $\delta_{\mathrm{Trade}_t}(\tau)=-\sum_{j=i+1}^{qi}\theta_i(\tau)$, $\gamma_{\mathrm{RNE}}(\tau)=\sum_{i=0}^{q1}\theta_i(\tau)$, and $\delta_{\mathrm{RNE}_t}(\tau)=-\sum_{j=i+1}^{qi}\theta_i(\tau)$.

The short-run dynamic parameters are mentioned in equation (3); we investigate the long-run relationship between environmental quality and economic complexity by modifying equation (3) into (4) which is as follows:

$$Q_{\mathrm{CE}_t}=\mu(\tau)+X_t'\beta(\tau)+M_t(\tau), \tag{4}$$

with $X=[\mathrm{ECI},\mathrm{FDI},\mathrm{GDP},\mathrm{Trade},\mathrm{RNE}]$ and $\beta_{\mathrm{ECI}}(\tau)=\gamma_{\mathrm{ECI}}(\tau)\left[1-\sum_{i=1}^{p}\Phi G_i(\tau)\right]^{-1}$ and $M_t(\tau)=\sum_{j=0}^{\infty}\nu_{\mathrm{ECI}_j}(\tau)\Delta\mathrm{ECI}_{t-1}+\sum_{j=0}^{\infty}\theta_{\mathrm{ECI}_j}(\tau)\Delta\epsilon_{t-1}$, with $\mu(\tau)=\alpha(\tau)\left[1-\sum_{i=1}^{p}\Phi_i(\tau)\right]^{-1}$ and $\nu_j(\tau)=\sum_{l=j+1}^{\infty}\pi_1(\tau)$. In the same way, we did calculation for $\beta_{\mathrm{FDI}}(\tau)$ and $\beta_{\mathrm{GDP}}(\tau)$, $\beta_{\mathrm{Trade}}(\tau)$, and $\beta_{\mathrm{RNE}}(\tau)$. $\{\mu_1(\tau),\mu_0(\tau),\cdots$ and $\{\{\theta_1(\tau),\theta_0(\tau),\cdots$ further explain as

$$\sum_{i=0}^{\infty}\theta_i(\tau)L^i=\left(1-\sum_{i=1}^{p}\Phi_i(\tau)L^i\right)^{-1},$$
$$\sum_{i=0}^{\infty}\pi_i(\tau)L^i=(1-L)^{-1}\left(\frac{\sum_{i=0}^{q_i}\omega_i(\tau)L^i}{1-\sum_{i=1}^{q_i}\omega_i(\tau)L^i}-\frac{\sum_{i=0}^{q_i}\omega_i(\tau)}{1-\sum_{i=1}^{q_i}\omega_i(\tau)}\right). \tag{5}$$

To resolve the issue of serial correlation, we move to one step further for QARDL as given in

$$\begin{aligned}Q_{\Delta\mathrm{CO}_{2,t}}=\ &\alpha+\rho\mathrm{CO}_{2,t-1}+\Phi_{\mathrm{ECI}}\mathrm{ECI}_{t-1}+\Phi_{\mathrm{FDI}}\mathrm{FDI}_{t-1}\\&+\Phi_{\mathrm{GDP}}\mathrm{GDP}_{t-1}+\Phi_{\mathrm{Trade}}\mathrm{Trade}_{t-1}+\Phi_{\mathrm{RNE}}\mathrm{RNE}_{t-1}\\&+\sum_{i=1}^{p}\Phi_i\Delta\mathrm{CO}_{2,t-1}+\sum_{i=1}^{q1-1}\omega_i\Delta\mathrm{OECI}_{t-1}\\&+\sum_{i=1}^{q2-1}\lambda_i\Delta\mathrm{FDI}_{t-1}+\sum_{i=1}^{q3-1}\theta_i\Delta\mathrm{GDP}_{t-1}\\&+\sum_{i=1}^{q4-1}\theta_i\Delta\mathrm{Trade}_{t-1}+\sum_{i=1}^{q5-1}\theta_i\Delta\mathrm{RNE}_{t-1}+\nu_t(\tau).\end{aligned} \tag{6}$$

There is still the possibility of concurrent correlation between $\nu_t$ and $\Delta\mathrm{ECI}_t$, $\Delta\mathrm{FDI}_t$, $\Delta\mathrm{GDP}_t$, $\Delta\mathrm{Trade}_t$, and $\Delta\mathrm{RNE}_t$. We can prevent prior correlations by using between $\nu_t$ projections on between $\Delta\mathrm{ECI}_t$, $\Delta\mathrm{FDI}_t$, $\Delta\mathrm{GDP}_t$, $\Delta\mathrm{Trade}_t$, and $\Delta\mathrm{RNE}_t$ in the form $\nu_t=\sigma_{\mathrm{ECI}}\Delta\mathrm{ECI}_t+\sigma_{\mathrm{FDI}}\Delta\mathrm{FDI}_t+\sigma_{\mathrm{GDP}}\Delta\mathrm{GDP}_t+\sigma_{\mathrm{Trade}}\Delta\mathrm{Trade}_t+\sigma_{\mathrm{RNE}}\Delta\mathrm{RNE}_t+\epsilon_t$. As a result, $\epsilon_t$ is no longer connected with $\Delta\mathrm{ECI}_t$, $\Delta\mathrm{FDI}_t$, $\Delta\mathrm{GDP}_t$, $\Delta\mathrm{Trade}_t$, and $\Delta\mathrm{RNE}_t$. The prior projections are incorporated into equation (6), which is then generalized into a quantile regression framework. As a result, the QARDL-ECM model looks like this:

$$\begin{aligned}Q_{\Delta\mathrm{CO}_{2,t}}=\ &\alpha(\tau)+\rho(\tau)\left(\mathrm{CO}_{2,t-1}-\beta_{\mathrm{ECI}}(\tau)\mathrm{ECI}_{t-1}\right.\\&-\beta_{\mathrm{FDI}}(\tau)\mathrm{FDI}_{t-1}-\beta_{\mathrm{GDP}}(\tau)\mathrm{GDP}_{t-1}\\&\left.-\beta_{\mathrm{Trade}}(\tau)\mathrm{Trade}_{t-1}-\beta_{\mathrm{RNE}}(\tau)\mathrm{RNE}_{t-1}\right)\\&+\sum_{i=1}^{p}\Phi_i(\tau)\Delta\mathrm{CCO}_{2,t-1}+\sum_{i=1}^{q1-1}\omega_i(\tau)\Delta\mathrm{ECI}_{t-1}\\&+\sum_{i=1}^{q2-1}\lambda_i(\tau)\Delta\mathrm{FDI}_{t-1}+\sum_{i=1}^{q3-1}\theta_i(\tau)\Delta\mathrm{GDP}_{t-1}\\&+\sum_{i=1}^{q4-1}\vartheta_i(\tau)\Delta\mathrm{Trade}_{t-1}+\sum_{i=1}^{q3-1}\mu_i(\tau)\Delta\mathrm{RNE}_{t-1}+\epsilon_t(\tau).\end{aligned} \tag{7}$$

The short-run cumulative effect on prior values of environmental quality on current value was measured by $\varnothing*=\sum_{i=1}^{p-1}\varnothing_j$. The estimation of short-run cumulative effect of current and previous level of economic complexity index, FDI inflow, GDP per capita, trade, and renewable energy on environmental quality is presented by $\varnothing*=\sum_{i=1}^{p-1}\varnothing_j$, $\omega*=\sum_{j=1}^{q1-1}\varnothing_j$, $\lambda*=\sum_{j=1}^{q2-1}\lambda_j$, $\theta*=\sum_{j=1}^{q3-1}\theta_j$, $\vartheta*=\sum_{j=1}^{q4-1}\vartheta_j$, and $\mu*=\sum_{j=1}^{q5-1}\mu_j$, respectively. The long-term cointegration of economic complexity index, FDI inflow, GDP per capita, trade, and renewable energy is $\beta_{\mathrm{ECI}}=-(\varnothing\mathrm{ECI})/\rho$, $\beta_{\mathrm{FDI}}=-(\varnothing\mathrm{FDI})/\rho$, $\beta_{\mathrm{GDP}}=-(\varnothing\mathrm{GDP})/\rho$, $\beta_{\mathrm{Trade}}=-(\varnothing\mathrm{Trade})/\rho$, and $\beta_{\mathrm{RNE}}=-(\varnothing\mathrm{RNE})/\rho$, respectively. Furthermore, the delta approach is used to compute the cumulative short-run parameters and long-term cointegrating parameters. The ECM parameter $\rho$ should be significantly negative.

Furthermore, we employed the Wald test which is used for statistical short- and long-run influences of ECI, FDI inflow, GDP, trade, and RNE on environmental quality. Through the Wald test, the null and alternate hypotheses of the parameters $\varnothing^*$, $\omega^*$, $\beta^*$, and $\rho^*$ are as follows:

$$\begin{aligned}&H_0^{\Phi}=F\Phi*(\tau)=f\ \text{versus}\ H_1^{\Phi}:F\Phi*(\tau)\neq f,\\&H_0^{\Phi}=S\omega*(\tau)=s\ \text{versus}\ H_1^{\Phi}:S\omega*(\tau)\neq s,\\&H_0^{\Phi}=S\beta_i*(\tau)=s\ \text{versus}\ H_1^{\Phi}:S\beta_i*(\tau)\neq s,\\&H_0^{\Phi}=S\rho_i*(\tau)=s\ \text{versus}\ H_1^{\Phi}:S\rho_i*(\tau)\neq s,\end{aligned} \tag{8}$$

where $F$ and $f$ are $h^*ps$ and $h^*$l, sometimes known as predefined matrices. $S$ and $s$ are $h^*s$ and $h^*$l, which are prespecified matrices with $h$ representing the number of limitations [68] and $l$ representing OP, GP, and FSI, respectively. We use the Wald test to investigate nonlinearities in the pace of adjustment parameter and long-run integrating parameter. For each group and parameter, we perform four tests.

*3.1. Data Sources and Descriptive Statistics: Empirical Analysis and Discussion.* For empirical analysis, the study collects the data from various sources for the period of 1970-2019 for Japan for the selected variables. The selection period of the data is based on the availability of data. The data were collected annually for all selected variables and

Table 1: Description of variables.

| Variables | Explanation | Sources |
|---|---|---|
| $CO_2$ | $CO_2$ emissions (metric tons per capita) | World Development Indicators |
| ECI | Observatory of economic complexity (2020) | https://oec.world/en/profile/country/japan/ |
| Renewable energy | Renewables per capita (kWh) | Raw data on energy consumption is sourced from the BP Statistical Review of World Energy. Available at: http://www.bp.com/statisticalreview |
| FDI | FDI (net inflows) to GDP (%) | World Development Indicators |
| Trade | Trade to GDP (%) | World Development Indicators |
| Income | GDP per capita (constant 2010 USD) | World Development Indicators |

Authors' computations.

Table 2: Descriptive statistics of the variables.

| Variables | $CO_2$ emissions | ECI | FDI inflow | Log GDP | Log trade | RNE |
|---|---|---|---|---|---|---|
| Mean | 8.277841 | 2.222334 | 0.119750 | 4.506253 | 1.226142 | 2.200093 |
| Median | 8.757196 | 2.311335 | 0.042725 | 4.592926 | 1.324891 | 2.150475 |
| Maximum | 9.893680 | 2.624820 | 0.831973 | 4.690198 | 1.574561 | 3.807995 |
| Minimum | 3.708021 | 1.718440 | -0.052908 | 4.084429 | 0.000000 | 0.000000 |
| Std. dev. | 1.439068 | 0.266494 | 0.193107 | 0.168716 | 0.440966 | 0.488448 |
| Skewness | -1.697861 | -0.308194 | 2.106279 | -0.875374 | -2.273020 | -0.495272 |
| Kurtosis | 5.575721 | 1.642272 | 7.140631 | 2.648963 | 6.699873 | 11.22707 |
| Jarque-Bera | 42.38563*** | 5.187842*** | 81.41111*** | 7.439467*** | 80.16295*** | 160.2205*** |

Note: *** represent the significance level at 1%, 5%, and 10%, respectively. Dependent variable: $CO_2$ emission represents environmental quality for Japan. Independent variables: ECI represents economic complexity index, FDI represents foreign direct investment inflow, log GDP represents GPD per capita, trade represents trade % of GDP, and RNE is renewables per capita (kWh).

then converted in quarterly data (1970Q1-2019Q4) using quadratic match sum method. Japan is one of the most developed countries, and its position ranked no. 1 in ECI index for the last two decades and ranked no. 3 in terms of GDP in 2018. $CO_2$ is used as dependent variable which is determined by number of factors such as environmental quality is the dependent variable; renewable energy and $CO_2$ have negative relationship; and the higher the renewable energy, the lower will be the $CO_2$ emission, whereas ECI, FDI inflow, trade, and income have positive association with environmental quality; that is, the higher the ECI, FDI inflow, trade, and income, the higher will be the $CO_2$ emissions. The data source of the selected study is reported in Table 1 while the descriptive statistic of variables, i.e., environmental quality, economic complexity index, FDI inflow, GDP per capita, trade, and renewable energy, is presented in Table 2. Among all variables, environmental quality shows maximum standard deviation and exhibits maximum volatility. Economic complexity, $CO_2$, GDP, trade, and renewable energy are negatively skewed, and FDI inflow is positively skewed.

The finding of platykurtic reveals that the data are fatter tails as compared to normal distributions. The results of the Jarque-Bera test statistic shows the significant deviations of the variable data from normal distributions which further proof that there is nonlinearity among all the variables. Therefore, the most suitable approach in that scenario is the QARDL [69, 71, 72].

## 4. Empirical Analysis and Discussion

We are using time series, and there is possibility of existing unit root in the data. Thus, before applying QARDL model of estimation, we examine the unit root test to determine the order of integration of the data. For that purpose, we perform the conventional augmented Dickey-Fuller (ADF) test and Phillips-Perron (PP) test. The ADF and PP test results are presented in Table 3; we use the Lee-Stratizich test for possible structural breaks in data, which is one comparatively advanced than ADF and PP test. The result of the Lee-Stratizich test is reported in Table 4. The findings of unit root show that all the variables are integrated at first order I(1). This fulfills the assumption for applications of QARDL method.

Table 5 shows the results of QARDL model estimations for Japan. The $\rho$ parameter of all quantiles indicates negative and significant association. It indicates dependency among the parameters. Furthermore, the findings reported that there is long-run association between ECI, FDI inflow, GDP, trade, REN, and $CO_2$ which is represented by $\beta$. The findings of ECI show that the first three quantiles from 0.05 to 0.50 show mix of positive and negative whereas

Table 3: Unit root analysis.

| Variables | ADF unit root test (with trend and intercept) Level | 1st difference | PP unit root test (with trend and intercept) Level | 1st difference |
|---|---|---|---|---|
| $CO_2$ | -4.277309 | -5.058011** | -3.988029 | -5.087704*** |
| ECI | -1.073723 | -6.853262*** | -1.167101 | -6.847236*** |
| FDI | 1.442312 | -5.800516** | -2.600703 | -13.38435*** |
| GDP | -1.112866 | -6.147628*** | -0.078184 | -5.739870*** |
| Trade | -2.890848 | -7.328560*** | -3.014961 | -7.330278*** |
| RNE | -0.557472 | -8.05813*** | -1.089400 | -6.555023*** |

Note: *** and ** represent level of significance at 1% and 5%, respectively.

Table 4: Lee-Stratizich unit root analysis at level.

| Variables | $T$-state | BD1 | BD2 | Critical value 0.01 | 0.05 | 0.10 |
|---|---|---|---|---|---|---|
| $CO_2$ | -7.787 | 02.03.1996 | 09.11.2011 | -7.391 | -5.63000 | -4.217 |
| ECI | -9.771 | 01.07.2001 | 25.08.2014 | -7.216 | -5.146 | -4.119 |
| FDI | -3.233 | 16.10.2008 | 13.02.2015 | -7.197 | -7.420 | 4.432 |
| GDP | -2.870 | 04.05.2009 | 20.12.2016 | -6.539 | -5.380 | -4.420 |
| Trade | -4.719 | 10.10.2003 | 22.04.2016 | -6.143 | -5.730 | -4.168 |
| RNE | -1.454 | 29.01.2000 | 11.08.2016 | -6.312 | -5.910 | -4.480 |

quantile from 0.60 to 0.90 indicates positive and significant relationship with environmental quality; this implies that increase in the ECI leads to increase in $CO_2$ emissions in Japan. Our findings are consistent with Martins et al. [35], Abbasi et al. [36], and Ahmad et al. [15] and claimed that economic complexity index contributes to the environmental quality degradation. Nevertheless, this finding is in opposite to the findings of Neagu [19] who found that there is negative association between ECI and $CO_2$. Foreign direct investment inflow indicates both positive and negative relations with environmental quality. Quantile from 0.05 to 0.50 does not influence environmental quality, whereas at 0.60, it shows negative and significant relationship, and quantile range from 0.70 to 0.95 indicates positive and significant relationship that an increase in FDI inflow increases $CO_2$ emission in Japan. There are mixed findings of the previous literature about FDI inflow and $CO_2$. The findings of this study are aligned with Zhang and Zhang [73] and Shahbaz et al. [74]; that is, FDI inflow increases $CO_2$ emission for China and the USA, respectively.

The GDP per capita also shows mixed association with environmental quality in which quantile range from 0.05 to 0.50 does not influence GDP per capita while quantile range from 0.60 to 0.95 shows positive and significant effect which implies that an increase in GDP per capita increases the $CO_2$ emissions. These outcomes are consistent with previous studies such as Balsalobre-Lorente et al. [53] and Ahmed et al. [54]; economic growth leads to increase in $CO_2$ emissions. The result of trade indicates both mixed positive and negative signs; that is, quantile range from 0.05 to 0.50 does not influence environmental quality whereas quantile ranges from 0.60 to 0.70 and 0.90 to 0.95 show positive and significant association with environmental quality which suggest that increase in trade leads to increase in $CO_2$ emission. The results are consistent with previous research of Fatima et al. [50] and Shahbaz et al. [74]; that is, increase in trade leads to increase in $CO_2$ emission. While quantile 0.80 has negative and significant effect on environmental quality, this suggests that with the expansion of international trade, countries have greater access to internal market which brings the competitions for better imports of technology which untimely leads to lower $CO_2$ emissions [75, 76]. According to Rahman and Vu [13], there is mixed evidence related to international trade and its effects on environment in both ways either positive or negative.

The results of RNE indicate that all quantiles are negative except 0.95 while quantile range 0.05-0.50 has effect on $CO_2$ emission and quantile 0.60-0.90 shows significant and negative result indicating that an increase in renewable energy leads to decrease in $CO_2$ emission of Japan. As one of the top world class technology innovative country, Japan has the potential to produce more cheap cost of renewable energy and becomes the leading country to cleaner environment. Japan is 6th in the world leading countries generating renewable energy; this is due to efficiency and sustainability in Japan's renewable energy generation system. In 2021, Japan's renewable energy contributes 22.4% of all electricity generated which is 10 points more as compared to 2012, i.e., 12.1%, while solar PV accounted for 9.3% electricity generated as compared to 2012 which is 1.9%. This development in renewable energy leads to lower the environmental pollution in Japan (JREC, 2021). These outcomes are in line with

Table 5: Results of QARDL (quantile autoregressive distributed lag) model.

| Quantiles ($\tau$) | Constant | ECM | Long-run coefficients | | | | | Short run coefficients | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | $\alpha^*(\tau)$ | $\rho^*(\tau)$ | $\beta_{ECI}(\tau)$ | $\beta_{FDI}(\tau)$ | $\beta_{GDP}(\tau)$ | $\beta_{Trade}(\tau)$ | $\beta_{RNE}(\tau)$ | $\partial_i(\tau)\Delta lnCO_2$ | $\gamma_i(\tau)\Delta lnECI$ | $\varnothing_i(\tau)\Delta lnFDI$ | $\delta_i(\tau)\Delta lnGDP$ | $\theta_i(\tau)\Delta lnTrade$ | $\sigma_i(\tau)\Delta lnRNE$ |
| 0.05 | 1.141 | -0.029*** | -0.3493 | 0.652 | -0.096 | -0.657 | -0.231 | 0.707 | -0.134 | -25.319 | 0.943 | 23.565 | 3.638 |
| 0.10 | -0.169 | -0.030*** | -1.278 | -0.523 | 1.048 | 0.294 | -0.734 | 0.431 | 1.196 | 1.998 | 0.8492 | -0.6129 | -1.890* |
| 0.20 | -0.414 | -0.206* | -0.192 | -2.012 | -0.966 | -0.572 | -0.441 | 0.593 | 4.513 | -0.415 | 0.891 | 2.572*** | 0.318*** |
| 0.30 | 1.749 | -0.063** | 0.3109 | 0.036 | -0.239 | -0.418 | -0.706 | 0.617 | 1.719 | -15.864 | 0.594 | 0.811 | 8.840*** |
| 0.40 | -0.529 | -1.593** | -0.025 | 0.3576 | 0.289 | 0.04 | -0.697 | 0.751 | 0.582 | 3.062 | 0.605 | -0.582** | 3.091 |
| 0.50 | -1.501* | -0.012*** | -0.413 | -0.157 | 0.427 | 0.032 | -1.363 | 0.418 | 0.172 | 5.092 | 0.616 | 1.165** | 7.728 |
| 0.60 | -0.651 | -0.081*** | 0.668* | -2.783** | 0.368* | 0.546*** | -1.479* | 0.372*** | 0.262 | 6.293 | -5.64 | 0.146 | 0.325*** |
| 0.70 | -0.542 | -0.417** | 0.636* | 0.162** | -0.186** | 0.093** | -0.181** | 0.591*** | -1.031 | 0.657 | -16.64 | 0.622 | 3.456 |
| 0.80 | -1.546 | -0.031*** | 2.962** | 0.508* | 0.021* | -0.166** | -0.697** | 0.370*** | 0.841* | 11.71 | 0.609 | 9.493 | 0960** |
| 0.90 | -0.448 | -0.117*** | 0.876*** | 0.038*** | 0.578** | 0.041* | -0.234* | 0.322*** | 0.436. | 0.858 | 11.719 | 8.609* | 4.234 |
| 0.95 | -0.333 | -0.050*** | 0.1843 | 0.722* | 0.302* | 0.439* | 0.068* | 0.710*** | 0.654 | 11.711 | 0.609 | 5.113 | 0.354 |

Note: the table represent the quantile estimations results. The standard errors are between brackets. ***, **, and * show 1%, 5%, and 10% significance level, respectively. ECM represents error correction term.

Table 6: Results of the Wald test for the consistency of parameters.

| Variables | Wald test | $p$ value |
|---|---|---|
| $\rho$ | 42.48*** | 0.001 |
| $\omega_{\ln ECI}$ | 34.76*** | 0.001 |
| $\omega_{\ln FDI}$ | 21.80 | 0.001 |
| $\omega_{\ln GDP}$ | 3.49 | 0.001 |
| $\omega_{\ln Trade}$ | 0.54*** | 0.001 |
| $\omega_{\ln RNE}$ | 5.26 | 0.001 |
| $\partial_i$ | 9.83*** | 0.001 |
| $\Delta$lnECI | 0.37 | 0.001 |
| $\Delta$lnFDI | 0.92 | 0.520 |
| $\Delta$lnGDP | 1.72 | 0.001 |
| $\Delta$lnTrade | 20.69*** | 0.001 |
| $\Delta$lnRNE | 0.81 | 0.001 |

Source: authors' estimations. ***, **, and * shows 1%, 5%, and 10% significance level respectively.

past studies such as Wang et al. [14]; that is, the top ten renewable energy-generating countries significantly reduce the $CO_2$ emissions. Sub-Saharan countries in long-run renewable energy reduce $CO_2$ emissions but in the short run shows bidirectional causality.

Moreover, environmental quality in short term indicates the positive effect; but the quantile 0.60-0.95 range from 0.60 to 0.95 significantly influences $CO_2$ emission in Japan. The economic complexity index prevails both positive and negative implications; however, quantile 0.80 shows a significant positive implication. Whereas past and current changes of both FDI inflow and GDP show positive and negative implications for GDP, it does not influence past and current variations in environmental quality at all quantiles. The current and previous changes in trade positively and significantly influence previous and current variations in environmental quality at quantile range 0.20, 0.50, and 0.90, respectively, whereas the past and current variations in the trade negatively and significantly influence the current and previous changes in environmental quality at quantile 0.40.

The prevailing and past changes in RNE have a positive and significant influences in the past and current changes in environmental quality at quantile 0.20, 0.30, 0.60, and 0.80, respectively. Overall, the outcomes of the QARDL model suggest that ECI, FDI inflow, GDP, trade, and RNE are positive and negative determinants of environmental quality both in the short run and long run with respect to Japan.

The short-run and long-run parameter dependency of the Wald test outcomes is reported in Table 6. The Wald test estimation outcomes reject the null hypothesis of linearity in the speed of adjustment parameters for Japan. The null hypothesis is rejected in the model for overall $\rho$. The Wald test analyzes the nonlinearity for describing locational asymmetries [71]. The findings of the Wald test in this study show that null hypothesis is rejected for long-run parameters for all the variables such as ECI, FDI inflow, GDP, trade, and RNE. It is the same for the short-run parameter that the Wald test rejects the null hypothesis for all variables ECI, FDI inflow, GDP, trade, RNE, and $CO_2$ which means that there is asymmetric and nonlinear association between them.

## 5. Conclusion and Policy Recommendation

This study explores the linkages between economic complexity, renewable energy, FDI, trade, and environmental quality in Japan. The economic complexity analyzes the structural properties of the mutual trade network and explains the income per capita gap across the globe. The economic complexity index (ECI) is an instrumental tool for predicting and explaining future growth, revenue, and greenhouse gas (GHG) emissions. Japan has achieved significant economic goals over the past few decades, with substantial implications for the country's $CO_2$ emissions. Applying the quantile autoregressive distributed lag (QARDL) model for analysis, this paper examines the relationship between economic complexity, renewable energy, FDI, trade, and environmental quality in Japan. The QARDL provides robust information on both long-term and short-term relationships between dependent and independent variables across different quantiles.

In this study, $CO_2$ emissions are used as the dependent variable, while GDP, FDI, renewable energy, and trade are treated as independent variables. In the short run, the ECI, FDI, GDP, renewable energy, and trade impact $CO_2$ emissions only in the last few quantiles. However, in the long run, FDI, GDP, and renewable energy do not significantly affect $CO_2$ emissions in Japan, while ECI only effects $CO_2$ emissions in the 8$^{th}$ quantile. Trade, on the other hand, shows a mixed effect on $CO_2$ emissions in the long run. This study's findings suggest that the expansion of economic activities such as GDP, FDI, and trade can negatively influence the environment, primarily because the economic expansion results in higher $CO_2$ emissions due to increased production. In contrast, the results suggest that renewable energy contributes to a reduction in $CO_2$ emissions, indicating its positive role in mitigating environmental degradation.

Our findings show that ECI and GDP per capita have a direct association with $CO_2$ emissions. This relationship could explain the substantial quantity of crude petroleum imports from countries such as Saudi Arabia, the United Arab Emirates, Kuwait, Qatar, and Russia. In contrast, Japan's major exports are machinery, large construction vehicles, hot-rolled iron, electrical capacitors, and disc chemicals for electronics to China, the US, South Korea, and Hong Kong. Firstly, given that the primary source of $CO_2$ emissions is production expansion within the country, it would be prudent for the government to impose a carbon tax as a control measure for $CO_2$ emissions. Secondly, promoting renewable energy production domestically would help meet the country's energy demands, particularly for the household and industrial sectors, while also supporting a cleaner environment. To encourage this, the government could consider offering tax exemptions for investments in renewable energy production. Thirdly, the Japanese government could incentivize trade activities focused on green products. This approach could potentially reduce the environmental impact of trade activities. Lastly, corporate tax exemptions on green export products could serve as an effective strategy for achieving both economic growth and environmental sustainability.

While Japan may not be a major polluter on a global scale, it is still a significant contributor to global emissions and faces unique challenges in reducing its carbon footprint. As a highly industrialized nation, Japan bears a responsibility to take proactive measures to decrease its greenhouse gas emissions and transition towards a more sustainable economy. Fortunately, Japan has made substantial progress in the development of innovative technologies and the implementation of policies aimed at reducing emissions. These efforts include promoting renewable energy sources, enhancing energy efficiency, and adopting carbon pricing mechanisms. Furthermore, Japan's active involvement in international climate negotiations positions it as a crucial player in shaping global climate policies. By examining Japan's approach to climate change, other nations can gain valuable insights into effective strategies and tactics employed in international climate negotiations. They can also learn from Japan's achievements and setbacks in order to refine their own approaches. Therefore, analyzing Japan's initiatives to reduce greenhouse gas emissions is vital for comprehending the challenges and opportunities that all countries face in transitioning towards a sustainable economy. While this study focuses solely on Japan, expanding the research to include multiple countries would enhance its scope and provide a more comprehensive understanding of the topic.

This study has some limitations. Firstly, employing panel countries and testing the theories within a specific region could offer valuable insights. Secondly, it is worth considering alternative analytical techniques rather than solely relying on the QARDL method. This would provide a more robust assessment of the subject matter. Lastly, it would be beneficial to distinguish and analyze the specific impacts of household and industrial $CO_2$ emissions within the region.

## Data Availability

The data used to support the findings of this study are available from the corresponding author upon request.

## Consent

The corresponding author and all the coauthors are willing to participate in this manuscript.

## Conflicts of Interest

The authors have declared no conflicts of interest for this article.

## Authors' Contributions

All authors contributed equally. All authors read and approved the final manuscript. M. H Shah conceptualized the study and wrote the original draft. H. D Chun, Yichu Wang, and I. Ullah supervised the study, wrote the original draft, and reviewed and edited the manuscript. Z. Fareed and S. T Hassan contributed to validation, methodology, and software. M. H Shah and I. Ullah were responsible for formal analysis, investigation, and resources. All authors have read and agreed to the published version of the manuscript.

## References

[1] K. Ahmed, M. Shahbaz, and P. Kyophilavong, "Revisiting the emissions-energy-trade nexus: evidence from the newly industrializing countries," *Environmental Science and Pollution Research*, vol. 23, no. 8, pp. 7676–7691, 2016.

[2] R. K. Kaufmann, B. Davidsdottir, S. Garnham, and P. Pauly, "The determinants of atmospheric $SO_2$ concentrations: reconsidering the environmental Kuznets curve," *Ecological Economics*, vol. 25, no. 2, pp. 209–220, 1998.

[3] M. Can, M. Ahmad, and Z. Khan, "The impact of export composition on environment and energy demand: evidence from newly industrialized countries," *Environmental Science and Pollution Research*, vol. 28, no. 25, pp. 33599–33612, 2021.

[4] U. EIA, *Energy Information Administration*, International Energy Outlook, US Department of Energy, 2018, September 2021, https://www.eia.gov/international/overview/country/IDN.

[5] World Bank, *World development indicators*, 2020, http://data.worldbank.org/country.

[6] Kizuna, *Clean Energy Strategy to Achieve Carbon Neutrality by 2050*, Government of Japan, 2022, https://www.japan.go.jp/kizuna/2022/06/clean_energy_strategy.html.

[7] Statista, "Environmental pollution in Japan-statistics & facts," 2021, https://www.statista.com/topics/7305/pollution-in-japan/.

[8] C. A. Hidalgo and R. Hausmann, "The building blocks of economic complexity," *Proceedings of the National Academy of Sciences*, vol. 106, no. 26, pp. 10570–10575, 2009.

[9] R. Hausmann, C. A. Hidalgo, S. Bustos, M. Coscia, and A. Simoes, *The Atlas of Economic Complexity: Mapping Paths to Prosperity*, Mit Press, 2014.

[10] R. Hausmann, C. Hidalgo, S. Bustos, M. Coscia, A. Simoes, and M. A. Yildirim, *The Atlas of Economics Complexity – Mapping Paths to Prosperity*, Center for International Development, Harvard University, Cambridge, 2011.

[11] N. Fatima, Y. Li, M. Ahmad, G. Jabeen, and X. Li, "Analyzing long-term empirical interactions between renewable energy generation, energy use, human capital, and economic performance in Pakistan," *Energy, Sustainability and Society*, vol. 9, no. 1, 2019.

[12] Z. Khan, S. Ali, M. Umar, D. Kirikkaleli, and Z. Jiao, "Consumption-based carbon emissions and international trade in G7 countries: the role of environmental innovation and renewable energy," *Science of The Total Environment*, vol. 730, article 138945, 2020.

[13] M. M. Rahman and X. B. Vu, "The nexus between renewable energy, economic growth, trade, urbanisation and environmental quality: a comparative study for Australia and Canada," *Renewable Energy*, vol. 155, pp. 617–627, 2020.

[14] Z. Wang, M. B. Jebli, M. Madaleno, B. Doğan, and U. Shahzad, "Does export product quality and renewable energy induce carbon dioxide emissions: evidence from leading complex

and renewable energy economies," *Renewable Energy*, vol. 171, pp. 360–370, 2021.

[15] M. Ahmad, Z. Ahmed, A. Majeed, and B. Huang, "An environmental impact assessment of economic complexity and energy consumption: does institutional quality make a difference?," *Environmental Impact Assessment Review*, vol. 89, article 106603, 2021.

[16] V. G. R. Chandran and C. F. Tang, "The impacts of transport energy consumption, foreign direct investment and income on $CO_2$ emissions in ASEAN-5 economies," *Renewable and Sustainable Energy Reviews*, vol. 24, pp. 445–453, 2013.

[17] B. A. Demena and S. K. Afesorgbor, "The effect of FDI on environmental emissions: evidence from a meta-analysis," *Energy Policy*, vol. 138, article 111192, 2020.

[18] B. Doğan, B. Saboori, and M. Can, "Does economic complexity matter for environmental degradation? An empirical analysis for different stages of development," *Environmental Science and Pollution Research*, vol. 26, no. 31, pp. 31900–31912, 2019.

[19] O. Neagu, "The link between economic complexity and carbon emissions in the European Union countries: a model based on the environmental Kuznets curve (EKC) approach," *Sustainability*, vol. 11, no. 17, p. 4753, 2019.

[20] J. P. Romero and C. Gramkow, "Economic complexity and greenhouse gas emissions," *World Development*, vol. 139, article 105317, 2021.

[21] M. B. Jebli, S. B. Youssef, and N. Apergis, "The dynamic linkage between renewable energy, tourism, $CO_2$ emissions, economic growth, foreign direct investment, and trade," *Latin American Economic Review*, vol. 28, no. 1, pp. 1–19, 2019.

[22] A. A. Haug and M. Ucal, "The role of trade and FDI for $CO_2$ emissions in Turkey: nonlinear relationships," *Energy Economics*, vol. 81, pp. 297–307, 2019.

[23] M. Shahbaz, Q. M. A. Hye, A. K. Tiwari, and N. C. Leitão, "Economic growth, energy consumption, financial development, international trade and $CO_2$ emissions in Indonesia," *Renewable and Sustainable Energy Reviews*, vol. 25, pp. 109–121, 2013.

[24] A. Kasman and Y. S. Duman, "$CO_2$ emissions, economic growth, energy consumption, trade and urbanization in new EU member and candidate countries: a panel data analysis," *Economic Modelling*, vol. 44, pp. 97–103, 2015.

[25] M. M. Rahman, "Do population density, economic growth, energy use and exports adversely affect environmental quality in Asian populous countries?," *Renewable and Sustainable Energy Reviews*, vol. 77, pp. 506–514, 2017.

[26] U. Shahzad, Y. Lv, B. Doğan, and W. Xia, "Unveiling the heterogeneous impacts of export product diversification on renewable energy consumption: new evidence from G-7 and E-7 countries," *Renewable Energy*, vol. 164, pp. 1457–1470, 2021.

[27] F. Seker, H. M. Ertugrul, and M. Cetin, "The impact of foreign direct investment on environmental quality: a bounds testing and causality analysis for Turkey," *Renewable and Sustainable Energy Reviews*, vol. 52, pp. 347–356, 2015.

[28] https://www.bp.com/content/dam/bp/business-sites/en/global/corporate/pdfs/energy-economics/statistical-review/bp-stats-review-2022-full-report.pdf.

[29] D. Azhgaliyeva, J. Beirne, and R. Mishra, "What matters for private investment in renewable energy?," *Climate Policy*, vol. 23, no. 1, pp. 71–87, 2023.

[30] G. Abu-Rumman, A. I. Khdair, and S. I. Khdair, "Current status and future investment potential in renewable energy in Jordan: an overview," *Heliyon*, vol. 6, no. 2, p. e03346, 2020.

[31] M. Ikram, W. Xia, Z. Fareed, U. Shahzad, and M. Z. Rafique, "Exploring the nexus between economic complexity, economic growth and ecological footprint: contextual evidences from Japan," *Sustainable Energy Technologies and Assessments*, vol. 47, article 101460, 2021.

[32] F. F. Adedoyin, I. Ozturk, F. V. Bekun, P. O. Agboola, and M. O. Agboola, "Renewable and non-renewable energy policy simulations for abating emissions in a complex economy: evidence from the novel dynamic ARDL," *Renewable Energy*, vol. 177, pp. 1408–1420, 2021.

[33] P. Mealy and A. Teytelboym, "Economic complexity and the green economy," *Research Policy*, vol. 51, no. 8, article 103948, 2022.

[34] L. K. Chu, "Economic structure and environmental Kuznets curve hypothesis: new evidence from economic complexity," *Applied Economics Letters*, vol. 28, no. 7, pp. 612–616, 2021.

[35] J. M. Martins, T. S. Adebayo, M. N. Mata et al., "Modeling the relationship between economic complexity and environmental degradation: evidence from top seven economic complexity countries," *Frontiers in Environmental Science*, vol. 9, 2021.

[36] K. R. Abbasi, K. Lv, M. Radulescu, and P. A. Shaikh, "Economic complexity, tourism, energy prices, and environmental degradation in the top economic complexity countries: fresh panel evidence," *Environmental Science and Pollution Research*, vol. 28, no. 48, pp. 68717–68731, 2021.

[37] Z. Ahmed and H. P. Le, "Linking information communication technology, trade globalization index, and $CO_2$ emissions: evidence from advanced panel techniques," *Environmental Science and Pollution Research*, vol. 28, no. 7, pp. 8770–8781, 2021.

[38] J. Swart and L. Brinkmann, "Economic complexity and the environment: evidence from Brazil," in *Universities and Sustainable Communities: Meeting the Goals of the Agenda 2030*, pp. 3–45, Springer, Cham, 2020.

[39] H. T. Naughton, "To shut down or to shift: multinationals and environmental regulation," *Ecological Economics*, vol. 102, pp. 113–117, 2014.

[40] A. A. Rezza, "FDI and pollution havens: evidence from the Norwegian manufacturing sector," *Ecological Economics*, vol. 90, pp. 140–149, 2013.

[41] D. K. Nguyen, T. L. D. Huynh, and M. A. Nasir, "Carbon emissions determinants and forecasting: evidence from G6 countries," *Journal of Environmental Management*, vol. 285, article 111988, 2021.

[42] S. R. Paramati, D. Mo, and R. Huang, "The role of financial deepening and green technology on carbon emissions: evidence from major OECD economies," *Finance Research Letters*, vol. 41, article 101794, 2021.

[43] U. Al-Mulali and C. F. Tang, "Investigating the validity of pollution haven hypothesis in the Gulf Cooperation Council (GCC) countries," *Energy Policy*, vol. 60, pp. 813–819, 2013.

[44] L. Jiang, H. F. Zhou, L. Bai, and P. Zhou, "Does foreign direct investment drive environmental degradation in China? An empirical study based on air quality index from a spatial perspective," *Journal of Cleaner Production*, vol. 176, pp. 864–872, 2018.

[45] C. F. Tang and B. W. Tan, "The impact of energy consumption, income and foreign direct investment on carbon dioxide emissions in Vietnam," *Energy*, vol. 79, pp. 447–454, 2015.

[46] M. Abdouli and S. Hammami, "Investigating the causality links between environmental quality, foreign direct investment and economic growth in MENA countries," *International Business Review*, vol. 26, no. 2, pp. 264–278, 2017.

[47] M. A. Nasir, T. L. D. Huynh, and H. T. X. Tram, "Role of financial development, economic growth & foreign direct investment in driving climate change: a case of emerging ASEAN," *Journal of Environmental Management*, vol. 242, pp. 131–141, 2019.

[48] J. W. Lee, "The contribution of foreign direct investment to clean energy use, carbon emissions and economic growth," *Energy Policy*, vol. 55, pp. 483–489, 2013.

[49] H. Zhu, L. Duan, Y. Guo, and K. Yu, "The effects of FDI, economic growth and energy consumption on carbon emissions in ASEAN-5: evidence from panel quantile regression," *Economic Modelling*, vol. 58, pp. 237–248, 2016.

[50] T. Fatima, U. Shahzad, and L. Cui, "Renewable and nonrenewable energy consumption, trade and $CO_2$ emissions in high emitter countries: does the income level matter?," *Journal of Environmental Planning and Management*, vol. 64, no. 7, pp. 1227–1251, 2021.

[51] M. G. S. Uddin, S. H. Bidisha, and I. Ozturk, "Carbon emissions, energy consumption, and economic growth relationship in Sri Lanka," *Energy Sources, Part B: Economics, Planning, and Policy*, vol. 11, no. 3, pp. 282–287, 2016.

[52] S. Hossain, "An econometric analysis for $CO_2$ emissions, energy consumption, economic growth, foreign trade and urbanization of Japan," *Low Carbon Economy*, vol. 3, no. 2012, pp. 92–105, 2012.

[53] D. Balsalobre-Lorente, M. Shahbaz, D. Roubaud, and S. Farhani, "How economic growth, renewable electricity and natural resources contribute to $CO_2$ emissions?," *Energy Policy*, vol. 113, pp. 356–367, 2018.

[54] K. Ahmed, M. Bhattacharya, Z. Shaikh, M. Ramzan, and I. Ozturk, "Emission intensive growth and trade in the era of the Association of Southeast Asian Nations (ASEAN) integration: an empirical investigation from ASEAN-8," *Journal of Cleaner Production*, vol. 154, pp. 530–540, 2017.

[55] C. C. Lee and J. D. Lee, "Income and $CO_2$ emissions: evidence from panel unit root and cointegration tests," *Energy Policy*, vol. 37, no. 2, pp. 413–423, 2009.

[56] M. Aydin, T. Degirmenci, and H. Yavuz, "The influence of multifactor productivity, research and development expenditure, renewable energy consumption on ecological footprint in G7 countries: testing the environmental Kuznets curve hypothesis," *Environmental Modeling & Assessment*, vol. 28, no. 4, pp. 693–708, 2023.

[57] T. Degirmenci and M. Aydin, "The effects of environmental taxes on environmental pollution and unemployment: a panel co-integration analysis on the validity of double dividend hypothesis for selected African countries," *International Journal of Finance & Economics*, vol. 28, no. 3, pp. 2231–2238, 2023.

[58] S. F. Razmi, B. R. Bajgiran, M. Behname, T. E. Salari, and S. M. J. Razmi, "The relationship of renewable energy consumption to stock market development and economic growth in Iran," *Renewable Energy*, vol. 145, pp. 2019–2024, 2020.

[59] N. Apergis, M. B. Jebli, and S. B. Youssef, "Does renewable energy consumption and health expenditures decrease carbon dioxide emissions? Evidence for sub-Saharan Africa countries," *Renewable Energy*, vol. 127, pp. 1011–1016, 2018.

[60] M. Kahia, M. B. Jebli, and M. Belloumi, "Analysis of the impact of renewable energy consumption and economic growth on carbon dioxide emissions in 12 MENA countries," *Clean Technologies and Environmental Policy*, vol. 21, no. 4, pp. 871–885, 2019.

[61] S. A. Raza and N. Shah, "Testing environmental Kuznets curve hypothesis in G7 countries: the role of renewable energy consumption and trade," *Environmental Science and Pollution Research*, vol. 25, no. 27, pp. 26965–26977, 2018.

[62] M. J. Alam, I. A. Begum, J. Buysse, S. Rahman, and G. Van Huylenbroeck, "Dynamic modeling of causal relationship between energy consumption, $CO_2$ emissions and economic growth in India," *Renewable and Sustainable Energy Reviews*, vol. 15, no. 6, pp. 3243–3251, 2011.

[63] S. Farhani, "Renewable energy consumption, economic growth and $CO_2$ emissions: evidence from selected MENA countries," *Energy Economics Letters*, vol. 1, no. 2, pp. 24–41, 2013.

[64] F. V. Bekun, "Mitigating emissions in India: accounting for the role of real income, renewable energy consumption and investment in energy," *International Journal of Energy Economics and Policy.*, vol. 12, no. 1, pp. 188–192, 2022.

[65] B. Quito, M. D. L. C. del Río, J. Álvarez-García, and F. V. Bekun, "Spatiotemporal influencing factors of energy efficiency in 43 European countries: a spatial econometric analysis," *Renewable and Sustainable Energy Reviews*, vol. 182, article 113340, 2023.

[66] U. K. Pata, "Renewable and non-renewable energy consumption, economic complexity, $CO_2$ emissions, and ecological footprint in the USA: testing the EKC hypothesis with a structural break," *Environmental Science and Pollution Research*, vol. 28, no. 1, pp. 846–861, 2021.

[67] F. V. Bekun, B. A. Gyamfi, S. T. Onifade, and M. O. Agboola, "Beyond the environmental Kuznets curve in E7 economies: accounting for the combined impacts of institutional quality and renewables," *Journal of Cleaner Production*, vol. 314, article 127924, 2021.

[68] J. S. Cho, T. H. Kim, and Y. Shin, "Quantile cointegration in the autoregressive distributed-lag modeling framework," *Journal of Econometrics*, vol. 188, no. 1, pp. 281–300, 2015.

[69] A. Razzaq, A. Sharif, N. Aziz, M. Irfan, and K. Jermsittiparsert, "Asymmetric link between environmental pollution and COVID-19 in the top ten affected states of US: a novel estimations from quantile-on-quantile approach," *Environmental Research*, vol. 191, article 110189, 2020.

[70] T. H. Kim and H. White, "Estimation, inference, and specification testing for possibly misspecified quantile regression," in *Maximum Likelihood Estimation of Misspecified Models: Twenty Years Later*, Emerald Group Publishing Limited, 2003.

[71] D. I. Godil, A. Sharif, M. I. Ali, I. Ozturk, and R. Usman, "The role of financial development, R&D expenditure, globalization and institutional quality in energy consumption in India: new evidence from the QARDL approach," *Journal of Environmental Management*, vol. 285, article 112208, 2021.

[72] X. He, S. Mishra, A. Aman, M. Shahbaz, A. Razzaq, and A. Sharif, "The linkage between clean energy stocks and the fluctuations in oil price and financial stress in the US and Europe? Evidence from QARDL approach," *Resources Policy*, vol. 72, article 102021, 2021.

[73] Y. Zhang and S. Zhang, "The impacts of GDP, trade structure, exchange rate and FDI inflows on China's carbon emissions," *Energy Policy*, vol. 120, pp. 347–353, 2018.

[74] M. Shahbaz, G. Gozgor, P. K. Adom, and S. Hammoudeh, "The technical decomposition of carbon emissions and the concerns about FDI and trade openness effects in the United States," *International Economics*, vol. 159, pp. 56–73, 2019.

[75] E. Helpman, "Explaining the structure of foreign trade: where do we stand?," *Weltwirtschaftliches Archiv*, vol. 134, no. 4, pp. 573–589, 1998.

[76] M. Shahbaz, H. H. Lean, and M. S. Shabbir, "Environmental Kuznets curve hypothesis in Pakistan: cointegration and Granger causality," *Renewable and Sustainable Energy Reviews*, vol. 16, no. 5, pp. 2947–2953, 2012.