World Journal of Advanced Research and Reviews
eISSN: 2581-9615 CODEN (USA): WJARAI
Cross Ref DOI: 10.30574/wjarr
Journal homepage: https://wjarr.com/

(Research Article)

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Does Japan's energy consumption impact its environmental degradation? Evidence from ARDL technique

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World Journal of Advanced Research and Reviews, 2025, 26(02), 234-253

Publication history: Received on 25 March 2025; revised on 30 April 2025; accepted on 02 May 2025

Article DOI: https://doi.org/10.30574/wjarr.2025.26.2.1544

Abstract

Using annual data from 1990 through 2021, this study looked into the roles of economic growth, energy use, globalization, and regulatory quality in Japan. In our analysis, we make use of the ARDL techniques. Using the ARDL, according to empirical data, GDP and fossil fuel have a positive and significant connection with CO_2, meaning any increase in GDP and fossil fuel will lead to increase in environmental degradation in the long-run. On the other hand, renewable energy has a negative and significant relationship with CO_2 in the long-run, meaning that, any increase in the consumption of renewable energy will reduce environmental degradation in Japan. While globalization and regulatory quality have negative and insignificant association with CO_2 in the lung-run. In the short-term, GDP, renewable energy, fossil fuel and globalization are all statistically significantly linked negatively to CO_2 emissions. Our study also uses FMOLS, DOLS and CRR analysis which also support the ARDL model. According to our findings with FMOLS, DOLS and CRR outputs, shows long run relationship between CO_2 and economic growth, renewable energy usage, use of fossil fuels, globalization, and trade openness in Japan. In addition, Pearson correlation was employed to test the connections between the variables. Our findings therefore give the Japanese government and the rest of the world additional information to help them think about renewable energy usage as the most reliable strategy to cut back on CO_2 emissions.

Key words: CO_2; GDP; Renewable energy; Fossil fuel; Globalization; Regulatory quality; and ARDL**.**

1. Introduction

Environmental degradation can interrupt the planet's carbon cycle and has an impact on global warming, which is causing governments around the world are starting to worry more and more about it. The most important issue facing humanity today is climate change. Climate change carried on by emissions of greenhouse gases (GHGs) demonstrates unparalleled hazards to development and human existence, mostly CO_2 pollutions (Hochman, et al., 2018). Extreme weather, animal extinction, and a lack of food are some of these threats. The principal human endeavor that contributes to CO_2 pollution is utilizing fossil fuels for energy (such as coal and natural gas) and transportation. Nevertheless, some business practices and land-use changes continue to produce CO_2 emissions. Only a few of the probable negative effects of global warming and climate change include stunted plant growth, increasing sea levels, disturbance of water systems, and adverse weather conditions (like heat waves, floods, storms, and droughts) (Romanello et al., 2021). Since the exorbitant cost of preserving wildlife and decontaminating landfills, a country could experience environmental degradation that could have negative consequences for the economy. Therefore, environmental preservation is one of the contemporary global problems that has been included into many countries' political systems.

Since environmental degradation can disrupt the global carbon cycle and contribute to global warming, it is a serious problem that is becoming more and more apparent on a global scale and is being considered by governments worldwide.

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Climate change is one of the most significant problems that humanity is now experiencing. Unprecedented threats to human progress and life are offered by climate change brought on by greenhouse gas emissions (GHGs), particularly CO_2 pollution (Dong et al., 2020). These hazards include severe weather, animal extinction, and a shortage of food. The primary human activity responsible for CO_2 pollution is the burning of fossil fuels for energy and transportation, such as coal and natural gas. However, some industrial operations and changes in land use continue to release carbon dioxide into the atmosphere. A few potential negative effects of climate change and global warming on human health, the environment, and ecosystems include sea level rise, disturbances to water systems, reduced plant growth, and extreme weather events (storms, floods, heatwaves, and droughts) (Romanello et al. 2022). International measures, such as the Paris Agreement and the Kyoto Protocol, have been developed by intergovernmental groups as a result of growing environmental consciousness worldwide. The major objective of the historic Paris Accord is to continue working toward a 1.5 °C global temperature increases while keeping it below 2 °C. (Khan & Hou, 2021).

Why Japan? There was a sudden increase rise in interest in sustainability in past few years, and there is ample scientific proof that human activity has an impact on the environment. Global warming is making Japan's typically mild temperature warmer, which is anticipated to significantly affect energy demand and related CO_2 emissions (Zhongming, et al.,2018). Japan ranks fourth internationally the largest importer of liquefied natural gas as well as coal and petroleum products. Domestic energy sources are scarce in Japan, accounting for less than 10% of the country's annual primary energy consumption as of 2012. World Bank, 2020: With a GDP of $US4.872 trillion in 2018, after China and the United States, Japan has the third-largest economy in the world, and is the seventh-biggest source of GHG emissions. After the Fukushima nuclear disaster in 2011, it put off its decarbonization efforts, which led it to abandon nuclear power and increase the use of fossil fuels. The Kyoto Protocol was ratified by the Japanese government in 2002, and began working to create a society with less carbon emissions. the Prime Minister of Japan as a result released a new vision in 2008 called " Approaches to a Low-Carbon Society," this also include making a long-run plan objective to reduce CO_2 emissions by 60 to 80 percent from the level in 1990 by 2050 (Sun & Yu, 2012). The earthquake that struck Great East Japan in 2011 and the Fukushima Daiichi nuclear power facility catastrophe exposed the weaknesses and stresses in Japan's energy supply infrastructure as well as the risks associated with nuclear power. The Fukushima nuclear tragedy prompted changes to the country's energy strategy, which would eventually reduce reliance on nuclear power, which produced around 30% of the nation's electricity in 2011 (Portugal-Pereira, & Esteban,2014).

This paper aims to investigate, in a single model, the relationships between CO_2, economic growth, energy consumption, globalization, and regulatory quality for the case of Japan, which has not been studied previously, particularly when regulatory quality is included as a control variable in the model. The ARDL econometric method will be used to achieve this goal. As far as we are aware, no research has used the ARDL approach before to collect information on the relationship—whether causal or dynamic—between the CO_2, globalization, regulatory quality, energy consumption, and economic growth in Japan at different frequencies and during different time periods. We also used FMOLS, DOLS, and CCR estimators to better capture the long-term effects of energy consumption, economic growth, globalization, and regulatory quality in Japan. As a result, this study fills in this vacuum in the literature. This study looked into the possibility that:

- The independent variables and CO2 have a long-term equilibrium relationship.
- The GDP, fossil fuels, and renewable energy have a substantial long-run effect on Japan's CO_2 and
- The FMOLS, DOLS, and CCR test findings corroborate the study's long-run estimates.

The rest of this study is organized as follows: The "literature review" section provides a quick overview of the most current studies conducted on the topic and the theoretical framework section. The section titled "Data Methodology" presents the data and methodology. The section under "Empirical findings" presents the conclusions from the empirical analysis. Lastly, the "concluding remarks" section presents the study's conclusion.

2. Synopsis of the literature review

Environmental deterioration is currently the world's biggest problem. CO_2 emissions, which are brought on by increase in energy demand, are the principal cause of environmental degradation.

2.1. Economic growth (GDP) and CO_2

Larger groups of developed economies have been observing differences in opinion over the past 20 years regarding the connection between CO2 emissions and GDP. It is obvious that basic industrialization means more emissions. On the other hand, the relationship between wealth and CO_2 is not very strong beyond this fundamental one. Consequently, several relationships amongst these variables are presented. We shall look at the tendency toward emission trajectories and economic growth in this study. The connection between economic growth and CO_2 emissions tests the Environmental Kuznet Curve (EKC) hypothesis, which depicts an inverted U-shaped non-linear curve between these two variables. Both in the beginning of development and once they have reached a certain stage of growth, these two variables have a positive relationship, according to the EKC, CO_2 emissions decrease as GDP increases since the nation can now purchase efficient technologies. This theory was put to the test, and it was found to be true by Akbostanci et al. (2009). Over the long-run, economic growth and CO_2 emissions are positively correlated.

Similarly, (Huang et al. 2008) provided evidence in favor of Kuznets' theory. After analyzing panel data on GDP and energy consumption from 82 countries between 1972 and 2002, the author came to the conclusion that there is no causal relationship between economic growth and energy consumption in low-income group nations. Pollution in low-income countries increases with income; additionally, pollution begins to decrease once a country reaches a specific income threshold. A research based on data gathered from 138 countries between 1971 and 2007 is presented by Wang (2013). The conclusion implies that carbon dioxide emissions can be explained by national incomes. The eventual gain in national GDP will translate into an increase in carbon dioxide emissions. In nearly 80% of the countries, the drive for economic expansion has led to a rise in carbon dioxide emissions.

Khan et al. in 2020 looked at the connection between Pakistan's energy use, economic growth, and CO_2 emissions. According to the findings, both in the short and long run, economic growth and energy use increase CO_2 emissions. Additionally, Khan et al.'s research from 2021 demonstrated that energy usage has a favorable effect on CO_2 emissions in 184 nations. However, the majority of research that explored this theory did so in favor of the EKC, including those by Ertugrul et al. (2016), and others. Rahman & Kashem (2017) also shown that there was a connection between economic growth, energy use, and CO2 emissions. As opposed to this, research by Soytas & Sari (2009), established a single direct relationship between CO_2 emissions, energy use, and economic growth.

2.2. Renewable energy and CO_2

One of the main concerns in the contemporary energy economy literature is how renewable energy affects environmental quality. For example, In the instance of 19 industrialized and developing countries, Apergis and Payne (2010) analyze the link between renewable energy, CO_2 emissions, economic growth and nuclear energy for the period 1984–2007. Granger's causality test results imply that renewable energy does not, in the short term, help to lower CO_2 emissions. Moreover, for a group of 12 MENA nations covering the period 1975–2008, Farhani (2013) evaluates the relationship between economic growth, renewable energy usage and CO2 emissions. The empirical findings demonstrate that, with the exception of one-way causation from renewable energy usage to CO_2 emissions, there is no short-term causal relationship between these variables. On the other hand, the long-term results also demonstrate unidirectional causality, extending from CO_2 emissions and economic growth to the use of renewable energy. Jin, (2022) investigate the viability of the EKC hypothesis for a group of 17 OECD nations for the years 1977–2010 by adding renewable energy as a new variable to the environmental equation. They discover that using more renewable energy can help cut carbon emissions, this finding also aligns with (Damak & Hasan 2023; Damak & Ewaede 2024; Ochanya & Damak 2025). Their results also refute the validity of the EKC theory. Moutinho and Robaina (2016) investigate the short- and long-term causal relationships between CO_2 emissions from power generation and real income for 20 European nations for the period 1991–2010; 2001–2010. The findings offer compelling proof of the EKC's validity and imply that renewable energy can both significantly lower CO_2 emissions and be a factor in the variations in the connections between emissions and income among European nations. Zoundi (2017) investigates the impact of renewable energy on environmental degradation for 25 African nations chosen between 1980 and 2012. According to their findings, renewable energy still works well in place of traditional fossil fuel energy despite having a negative short-term impact on CO_2 emissions. Using an ARDL cointegration approach, Belaïd and Youssef (2017) investigate the link between CO_2 emissions, renewable and non-renewable energy consumption, and economic growth in the context of the Algerian economy over the 1980–2012 period. Their findings demonstrate that economic expansion and the long-term effects of non-renewable energy usage on CO2 emissions are negative. The findings also suggest that utilizing sustainable energy sources can improve the surrounding environment. Kahia et al. (2017) examines the causal connections between economic expansion and sustainable energy using data for MENA nations and demonstrate that renewable energy boosts economic growth while lowering CO_2 emissions. Recently, Damak & Hasan (2023) globalization and energy consumption in Japan; Chen et al. (2019) investigate China's 1980–2014 increase of the economy, the amount of energy produced, both renewable and non-renewable, and international commerce. According to their research, carbon emissions rise with increases in non-renewable energy and per capita GDP but fall with increases in renewable energy.

2.3. Fossil fuels and CO_2

The changes in carbon dioxide emissions from burning fossil fuels (coal, gas, and oil) in 28 European countries from 1960 to 2018 are displayed in this literature study by Andrew, (2020). Although the need for coal and oil still dominates the energy sector, the importance of natural gas and renewable energy sources is growing. One-third of all energy use was made up of natural gas in 2018; between 1960 and 2018, this percentage rose from 1.94% to 28.05%. Germany was the world leader in CO_2 emissions in 2018 with 759 Mt, followed by the UK (379 Mt), Poland (344 Mt), Italy (338 Mt), and France (379 Mt). In 2018, Germany's CO_2 emissions exceeded six times the annual average of 123 million tons of CO_2. Out of all the countries, only seven have carbon dioxide emissions that surpass the annual average, while 21 have emissions that are considerably lower than the average for 2018. As to the data, the CO_2 emissions of the Czech Republic and Latvia increased by a meagre 7% between 1960 and 2018, but the countries of Cyprus, Portugal, Greece, and Spain experienced the highest growth. In contrast, Italy saw the largest increase in CO_2 emissions (229 Mt CO_2), followed by Spain (219 Mt CO_2) and Poland (144 Mt CO_2). Nevertheless, just four of the 28 nations under investigation—Germany, Luxembourg, Sweden, and the United Kingdom—had CO_2 emissions in 2018 that were comparable to or lower than those in 1960.

Additionally, carbon emissions and fossil fuels are discussed. For instance, according to Druckman and Jackson's 2009 study, CO2 emissions fell in the first half of the 1990s when examining the carbon footprint of families in the United Kingdom between 1990 and 2004, due to fuel replacements in the electric sector. But since then, more products and services have come to include CO_2 emissions, which have been rising. Zhang, & Wang, (2017) comparison of energy usage to Danish family consumption between 1966 and 1992 showed that the effect of increased overall use was substantially compensated by lowering energy intensity within the industries producing goods, with the changing composition of consumption having a far lesser role. In contrast, Baiocchi, (2010) concentrated on a shorter period of time for the US, namely from 1997 to 2004, and found that structure had a greater influence than shifting sectoral energy intensities.

2.4. Globalization and CO_2

The global output is steadily increasing as globalization and industrialization progress. Globalization is the term used to describe how national economies are integrated regarding commerce, financial flows, and further political and socioeconomic facets, with the global economy. Multiple ways exist for globalization to impact environmental quality. According to Shahbaz et al. (2017), there are various environmental issues that are related to globalization. Many environmentalists believe that increased globalization encourages consumer demand for products and services grows along with economic activity and output. This causes both environmental damage and the depletion of natural resources (Damak & Hasan 2024). Environmental benefits of globalization were discovered by Dogan and Turkekul (2016). In addition, globalization has been found by Sharif et al. (2020) to have detrimental environmental externalities. Additionally, in contrast to the political, social, economic and globalization index, urbanization has a negative impact on CO_2 emissions, according to Dauvergne's (2008) analysis. However, Dogan and Deger (2016) and others came to the opposite conclusion, that the transmission of environmentally favorable technologies, which is made feasible by globalization, can improve environmental quality, and stressing how globalization has a major negative influence on CO_2 emissions.

2.5. Regulatory quality and CO_2

The greatest strategy to promote excellent environmental practices, according to many experts, is through state environmental regulations combined with effective monitoring and unambiguous penalties for non-compliance. (2013) Zapata et al.According to some research conducted in the past few years, institutional pressures have an effect on business environmental practices Berrone & Gomez-Mejia, (2009). Comparably, research by Khanna and Anton (2002) and Delmas & Toffel (2004) indicates that institutional quality, which includes "coercive pressure, normative influence or mimicry," can affect how quickly environmental actions spread throughout high-pollution firms in an economy, including the observance of sound ecological management plans. However, detractors contend that institutional measures like third-party inspection, public humiliation, and penalties can only produce isomorphic adherence to environmental compliance norms within an economy Delmas et al., (2019). They typically assert that proactive laws enhance innovation-based performance over time, whereas reactionary methods increase corporate environmental performance in the short term. They also argue that businesses looking to engage in sustainability through legislation are essentially simply facing challenges to their regular business operations. They discover, however, that products and processes are redesigned, controlling systems include fresh data sets, communication strategies are updated, and knowledge and values systems want fresh information. Thus, firms understand that organizational learning—rather than regulations—is a key tool for efficiently realizing environmental sustainability in their operations Siebenhüner & Arnold (2007). Discussions about corporate sustainability delivery in recent years have typically called for "total organizational redesign and approaches," which ask for the capacity for adaptation and learning van Marrewijk & Hardjono (2003).Moreover, a lot of experts in sustainability delivery think that the implementation of mandatory environmental laws with strong monitoring and clear consequences for non-compliance typically shows useful instruments for guaranteeing that people and businesses implement sustainable environmental practices Chams & García-Blandón (2019). Tatoglu et al. (2020) assert that the capacity of politicians to control corporate behavior in an economy through the absence of laws and fines is important. Analogously, it has been observed that individuals and organizations are significantly motivated to participate in voluntary environmental activities when they are aware of environmental legislation and get incentives for taking action beyond compliance with environmental concerns (Tatoglu et al., 2020). For instance, institutional rules governing the automobile sector often guarantee a decrease in atmospheric pollutants and mandate that businesses modify and implement sustainable manufacturing practices or do away with negative emissions by creating eco-friendly products like electrical and hydrogen-powered vehicles. Critics counter that organizations either deliberately manipulate public institutions or rebel against institutional oversight and regulations Bui & Fowler, 2019; Ryngelblu et al. (2019). Oliver (1991) states that this kind of resistance typically takes the form of openly challenging enforced standards, suing institutions, launching legal challenges, or directly attacking institutional restrictions.

Regulations pertaining to fossil fuels are imposed on people and corporations in the context of environmental sustainability organizations with the goal of lowering greenhouse gas (GHG) emissions. However, other experts say that in regard of multinational enterprises, pushing every environmental agency and government to lower regulation requirements is not practicable in recent times Bunea & Chrisp (2023). Furthermore, consumers reject and denounce companies that offer subpar and environmentally harmful goods and services because they care about the environment Delmas & Toffle, (2004a).

It is clear using the reviewed literature that the conclusions are contradictory, highlighting the need for additional research on the connections between CO_2 emissions and regulatory quality, the globalization index, economic growth, and energy use. To the authors' knowledge, no previous research has looked at the effects of economic growth, energy consumption, the globalization index, and regulatory quality on CO_2 emissions in Japan using the ARDL model. Consequently, the present work fills a knowledge gap in the field. This research explores the connections between CO_2 and regulatory quality, the globalization index, economic growth, and energy use. This empirical study's dataset includes data from 1990 through 2021.

3. Theoretical Framework

According to the debate over environmental protection and economic growth, the fundamental driver of income growth is the combination of factors that affect production which increases businesses' required inputs that create pollution (Lopez 2017). Based on the more comprehensive Environmental Kuznets Curve (EKC) paradigm (Kuznets 1955), economic growth and environmental quality are related in both positive and negative ways. The idea contends that while a positive outcome is anticipated in the short term, a negative outcome is anticipated in the long term (Grossman & Krueger, 1991). The scale effect has a positive association, whereas the technique effect has a negative one, according to Udeagha & Muchapondwa (2022). This suggests that, in the short term, as the agricultural sector expand, the environment will also get worse; however, as wealth increases, Production technique will shift away from being extremely industrialized, which produces more emissions, and toward being more service oriented, which produces fewer emissions. But doing so hurts the economies of less developed countries. As stated by the "pollution haven" theory, less developed nations with laxer environmental rules receive industrial operations that are hazardous to the environment from wealthy nations (Bardi & Hfaiedh 2021). The fundamental cause of this is that when earnings rise, people place greater importance on to improve their standard of living and increase pressure on the government to enact environmental protection laws. According to Usman et al. (2022), businesses with shoddy green technology often relocate to underdeveloped nations, which is bad for the environment. The pre-industrial uptrend stage, which is characterized by low income (caused by economic inefficiencies), the phase of industrial mass production, where the post-industrial green stage and rising income are prominent, which is characterized by rising income but more environmentally friendly technology, are the three stages of the EKC (Dinda, 2004). Openness to trade has grown in popularity has grown over time and demonstrated to be crucial to economic growth. Early in the 1980s, economic liberalization policies have been driven by the debt issue in the vast majority of developing nations. Trade has improved and GDP growth has increased as a result of Asian economies' initiatives for global opening up (Tissot et al., 2019). Growth, trade, and renewable energy work together to create an environment that has a snowball effect. Therefore, trade may promote the growth of renewable energy, which in turn can promote its use, which in turn can promote even more renewable energy production. The supply, demand, imports, and exports are only a few of the variables that have an effect on the energy markets frequently (Vanham et al. 2019). It is better for the environment if agricultural economic growth occurs concurrently with the growth of the renewable energy industry since it produces energy more cleanly.

On the basis of this structure, the research makes an effort to evaluate the nature of the interaction between the agricultural economy, the production of renewable energy as a consumption stimulant, the environment, and trade.

4. Data Presentation

This research does an empirical analysis of the multivariate time series technique. To solve the time series issues, the series are transformed into the form of a natural logarithm. We use the Autoregressive Distributed Lag (ARDL) model, Fully Modified Ordinary Least Square (FMOLS), Dynamic Ordinary Least Square (DOLS), and Canonical Cointegrating Regression (CCR). A common application of ARDL models is in time series data. Because there are 80 or fewer findings in the Pesaran, Shin, and Smith (2001) established ARDL co-integration procedure compared to the "two-step" method procedure for co-integration by Engle and Granger (1987), it is claimed to be more stringent in small samples typical of the social sciences. This claim states that when using an error correction form for an ARDL model, co-integration testing becomes essential. Despite this, this co-integration indicator is not directly used in conventional statistical applications. The ARDL paradigm's error-correcting method, in addition to its inherent inconsistencies, various lags, and lagging requirements, may be unduly complex. As a result, it gets harder to analyze the effects of changing the independent variable or variables, especially over the long and short terms. In order to combat this, an added programmable feature gives users the ability to dynamical imitate a variety of ARDL techniques while simultaneously including the model for rectifying errors.

Here are how the models are shown:

$$CO_2 = f\ (GDP, REW, FOSSIL, GLOBA, RQ) \quad \ldots\ldots\ldots \qquad (1)$$

To remove data discrepancies and make it simpler to assess the outcomes, every variable is transformed to their log forms. Energy usage encompasses consumption of fossil fuels, which stands in for the usage of nonrenewable energy and renewable energy sources.

$$LNCO2 = \alpha_0 + \Upsilon_1 LNGDP + \Upsilon_2 LNREWB + \Upsilon_3 LNFOSSIL + \Upsilon_4 LNAGLOBA + \Upsilon_5 LNRQ + \mu_t \qquad (2)$$

The term "natural log" (LN), α_0 indicates intercept, $\Upsilon_1 - \Upsilon_5$; shows the slope of the parameters μ_t= stochastic variable or disturbance variable and the apriori assumptions are supposed to be $\Upsilon_1 > 0$ - $\Upsilon_5 > 0$. Equation (1) uses LNGDP to represent economic growth and $LNCO_2$ to represent carbon dioxide emissions. LNREWB for consumption of renewable energy, LNFOSSIL for consumption of nonrenewable energy, LNGLOBA for economic, social, and political dimensions are taken into consideration to produce the globalization index. Each of the three components of globalization are political, social, and economic—makes up 26%, 38%, and 36% of the whole. This evaluation is based on Dreher (2006), and LNRQ for regulatory quality in Japan. Table 1 provides detailed information on the variables under investigation. All of the variables are sourced from the World Bank Indicator (https://data.worldbank/) and Swiss Economic Institute (SEI) https: indicators/kof-globalisationindex. html

Table 1 Variables sources

Variables	Details of the Variables	Measuring Instruments	Sources of Data
$LNCO_2$	Carbon dioxide	Percentage (%)	World Dev. Ind.
LNGDP	Economic growth	Constant 2015 US$	World Dev. Ind.
LNFOSSIL	Fossil fuel	Percentage (%) of total	World Dev. Ind.
LNREWB	Renewable energy	Percentage (%) of energy consumption	World Dev. Ind.
LNGLOBA	Globalization	Percentage (%)	KOF SEI
LNRQ	Regulatory quality	Estimate	World Dev. Ind.

All of the variables in World Development Indicators, are in logarithmic form and KOF Index of Globalization.

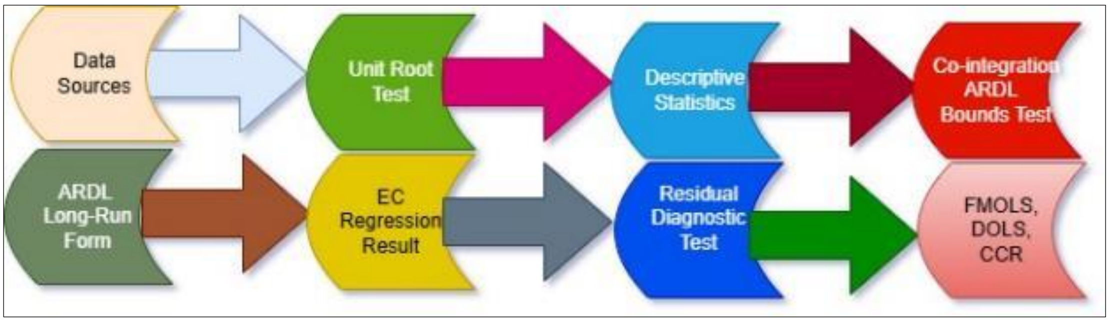

Figure 1 The analysis's workflow chart

4.1. Unit Root Test

Spurious regression will occur if the problem of non-stationarity in time series is not addressed Nelson and Plosser (1982). Variables with a unit root generated erroneous interpretations. It is necessary to perform a seasonal unit root test to make sure that there are no integrated series of order 2 or higher in order to address the explosiveness problem. In other words, if the outcomes show that the initial difference doesn't have a unit root and the series is stationary at levels I(0) and I(1). Because of the level of stationarity discovered in a combination of order levels I (0) and I(1), the ARDL approach is suitable for the inquiry (Jordan & Philips 2018). To test the unit root, the augmented Dickey-Fuller (ADF) frameworks were utilized. Although structural fractures are not taken into account by conventional stationarity testing, the data did not show any. A series reaches stationarity when the mean, variance, and covariance are all constants. The ADF and Philips – Perron (PP) findings demonstrating that each variable is integrated at I (0) and I (1) is one of the motivations for using ARDL method.

$$\triangle Y_t = \beta_{Dt} + {}_{\pi}\triangle Y_{t-1} + \sum_{j=1}^{p} \theta \triangle Y_{t-1} + \varepsilon_t \quad \text{.............(3)}$$

$$\triangle Y_t = {}_{(p-1)} Y_{t-1} + \varepsilon_t \quad \text{........... (4)}$$

Equation 3 represents the ADF test equation for the unit root, and Equation 4 represents the PP, which are used to confirm the stationarity of the data series. The first difference operator is represented by the symbol △, and Y_t shows a significant amount of time-related autocorrelation. The independent variables are denoted by Y_{t-1}. The error term is denoted by εt in Equations 3 and 4.

Table 2 ADF

Variable at Level	Constant	Prob.	Constant & trend	Prob.	Remark
LN CO_2	-2.567	0.111	-2.359	0.392	-
LNGDP	-1.573	0.484	-3.163	0.110	-
LNREWB	0.243	0.971	-2.009	0.574	-
LNFOSSIL	-0.450	0.887	-2.620	0.275	-
LNAGLOBA	-2.390	0.153	-1.816	0.673	-
LNRQ	-1.5767	0.4818	-3.1081	0.1226	-
	First Difference				
D(LN CO_2)	-4.709	0.001***	-3.728	0.039**	I (1)
D(LNGDP)	-5.755	0.000***	-5.666	0.000***	I (1)
D(LNREWB)	-6.434	0.000***	-7.627	0.000***	I (1)
D(LNFOSSIL)	-4.435	0.001***	-4.546	0.006***	I (1)
D(LNGLOBA)	-5.3303	0.000***	-5.9153	0.000***	I (1)
D(LNRQ)	-4.497	0.002***	-4.0001	0.019**	I (1)

Source: Author's Compilation, E-views 12

Table 3 PP

Variable at Level	Constant	Prob.	Constant & trend	Prob.	Remark
LN CO_2	-2.3614	0.1604	-2.0141	0.5711	-
LNGDP	-1.7331	0.4054	-2.7620	0.2209	-
LNREWB	0.7006	0.9902	-1.5025	0.8070	-
LNFOSSIL	-0.6561	0.8433	-2.0404	0.5572	-
LNGLOBA	-5.5309	0.0001	-1.4323	0.8308***	I (1)
LNRQ	-1.2522	0.6386	-2.3533	0.3950	-
	First Difference				
D(LN CO_2)	-4.6710	0.0008	-6.5447	0.0000***	I (1)
D(LNGDP)	-8.1353	0.0000	-8.9904	0.0000***	I (1)
D(LNREWB)	-5.7649	0.0000	-7.4625	0.0000***	I (1)
D(LNFOSSIL)	-4.0087	0.0043	-4.8440	0.0027***	I (1)
D(LNGLOBA)	-5.3515	0.0001	-12.0740	0.0000***	I (1)
D(LNRQ)	-4.3045	0.0021	-4.3475	0.0089***	I (1)

Tables 2 and 3 show that the variables were examined using the logarithm form, p-values, and t-statistics. The asterisks (***) and (**) denote significance values of 1% and 5%.

According to Table 2, the series is stationary. Applying a significance criterion of 5%, the outcome of the ADF and PP tests show that a unit root does not exist. The null hypothesis is disproved at the 5% level of significance because all of the variables are stationary at the first differences, I (1) except LNGLOBA that is stationary at I (0) using PP.

Each variable was evaluated using p-values, t-statistics, and the logarithm form. The asterisks (***) & (**) table 2 and 3 indicates that the expectation that it has been rejected, hence at the 1% and 5% significance levels, the variables have unit roots. The unit root model, which was developed to describe the generic model form, began with the intercept parameter, where each model displays a trend, as seen in table 2 and 3. Additionally, it had been shown that one variable is stationary at level and all other variables were either first-order integrated or stationary at the initial difference.

4.2. Descriptive Statistics and Spikes of the Variables

Table 4 Descriptive Statistics

	LN CO_2	LNGDP	LNREWB	LNFOSSIL	LNGLOBA	LNRQ
Mean	13.96808	10.38724	1.556560	4.452159	4.232102	6.362516
Median	13.97173	10.39599	1.490159	4.423036	4.244342	6.350415
Maximum	14.04883	10.49453	2.039921	4.550009	4.360103	6.526504
Minimum	13.89392	10.25493	1.252763	4.374482	4.014806	6.219704
Std. Dev.	0.041210	0.068333	0.233424	0.065606	0.102458	0.106301
Skewness	-0.032561	-0.14310	0.848508	0.556976	-0.559245	0.276946
Kurtosis	2.136550	1.972259	2.494635	1.531733	2.193060	1.490351
Jarque-Bera	0.999716	1.517548	4.180341	4.528928	2.536229	3.447779
Probability	0.606617	0.468240	0.123666	0.103886	0.281362	0.178371
Observations	32	32	32	32	32	32

Table 4 above is the descriptive statistics which were utilized to gather more information about how the data are spread out and distributed that were employed in the analysis during the study period. The descriptive statistics mean, median, max, min, std, skewness, kurtosis, Jarque-Bera, and probability values are examined in the study that follows. Table 4 above displays the descriptive statistics for each variable, where the dependent variable's mean LN CO_2 13.96 and the std. dev. is 0.04. The independent variables' mean values of LNGDP, LNREWB, LNFOSSIL, LNGLOBA, LNRQ were 10.39,1.56,4.45,4.23 and 6.36 respectively, and the std, were 0.07,0.23, 0.07, 0.1. and 0.11 respectively. LNREWB, LNFOSSIL and LNRQ are positively skewed, while LN CO_2, LNGDP, and LNGLOBA are all negatively skewed. While the Jarque-Bera test for normality was more than 1% and the probability values are more than 5%, which indicate the Kurtosis value for each variable was under 3, indicating that each had a normal distribution.

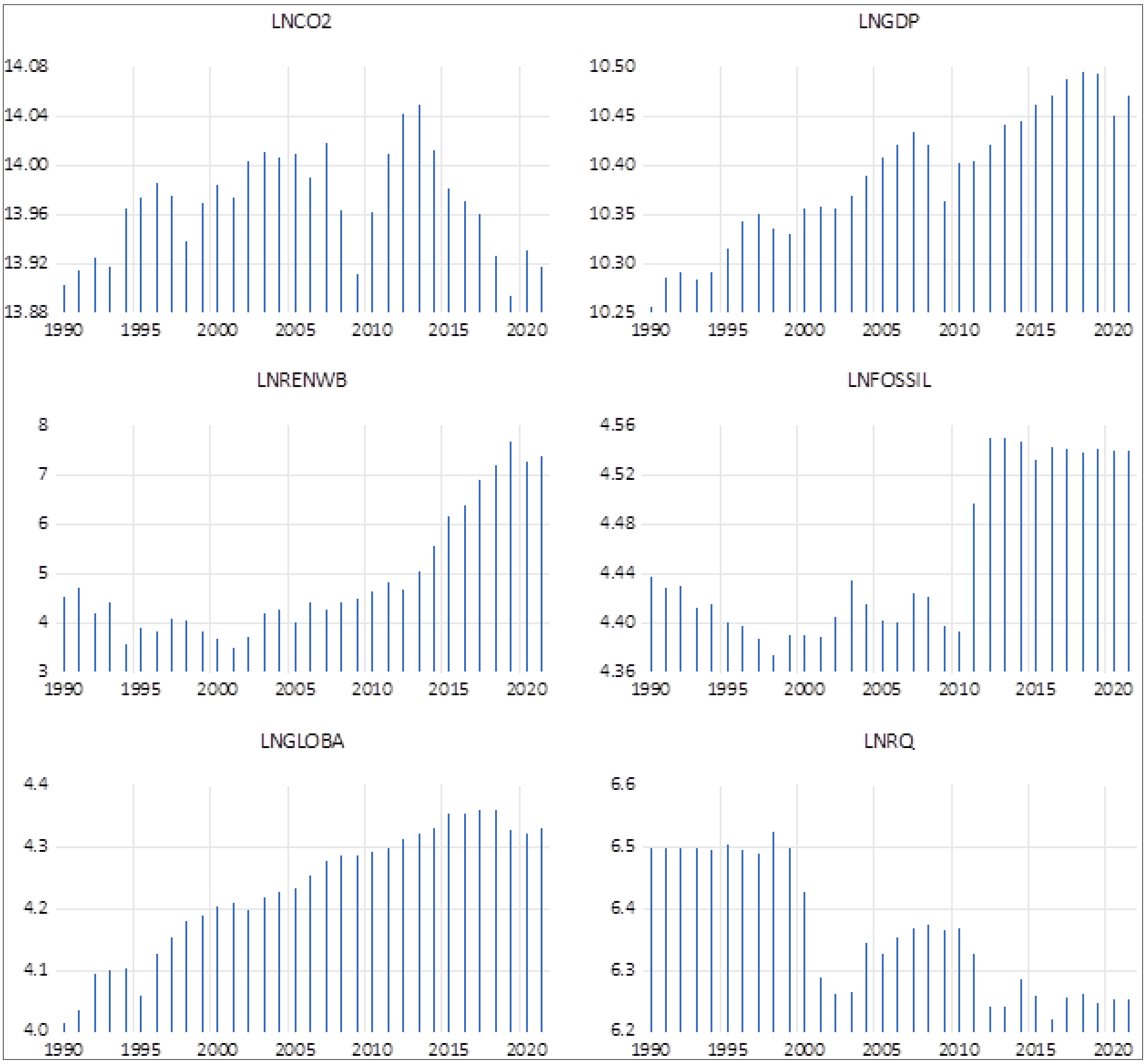

Figure 2 Owing to fluctuations in the independent variables, figure 2 above displays the series' spikes and a seasonal pattern in LNCO2. With a structural break in both 2010 and 2020, the LNGDP shows an increasing trend. Comparably, LNREWB exhibits an expected rising pattern, while LNFOSSIL has a seasonal tendency with a consistent increase from 2010 to 2020. LNGLOBA has a rising pattern. Although LNGOBA and LNRQ exhibit a declining tendency in this research, they are statistically insignificant over the long term when it comes to Japan in our analysis.

4.3. Co-integration Using a Bounds Examination Approach

The cointegration test looks for an equilibrium state across the long-run connection involving the independent and dependent variables. There are only variables that are integrated in the same order, when applying tests such as those by Engle & Granger (1987), and Johansen (1988). Pesaran et al. (2001) did, however, offer a resolution for the variables' cointegration with different orders using the ARDL- limited testing approach. Since no series is I(2), even in the case where the variables are organized differently, the cointegration test can still be carried out even if some of the variables are I(0) stationary and others are I(1) stationary.

Short-run equation

$$\Delta LNCO2_t = \alpha_0 + \sum_{i=1}^{q_1} \Upsilon_1 \Delta LNGDP_{t-i} + \sum_{i=1}^{q_2} \Upsilon_2 \Delta LNREWB_{t-i} + \sum_{i=1}^{q_3} \Upsilon_3 \Delta LNFOSSIL_{t-i} + \sum_{i=1}^{q_4} \Upsilon_4 \Delta LNGLOBA_{t-i} + \sum_{i=1}^{q_5} \Upsilon_5 \Delta LNRQ_{t-i} \quad (5)$$

Long-run Equation:

$$LN\ CO_{2t} = \alpha_0 + \Psi_1 LNCO2_{t-1} + \Psi_2 LGDP_{t-1} + \Psi_3 LNRENEWB_{t-1} + \Psi_4 LNFOSSIL_{t-1} + \Psi_5 LNGLOBA_{t-1} + \Psi_6 LNRQ_{t-1} + \mu_t \quad (6)$$

LaggedResiduals: $Z_{t-1} = LNCO2_{t-1} - \Psi_1 LGDP_{t-1} - \Psi_2 LNRENEWB_{t-1} - \Psi_3 LNFOSSIL_{t-1} - \Psi_4 LNGLOBA_{t-1} - \Psi_5 LNRQ_{t-1}$ (7)

$$\Delta LNCO2_t = \alpha_0 + \sum_{n=1}^{p} \Delta LNCO2_{t-1} + \sum_{n=1}^{q_1} \Upsilon_2 \Delta LNGDP_{t-1} + \sum_{n=1}^{q_2} \Upsilon_3 \Delta LNRENEWB_{t-1} + \sum_{n=1}^{q_3} \Upsilon_4 \Delta LNFOSSIL_{t-1} + \sum_{n=1}^{q_4} \Upsilon_5 \Delta LNGLOBA_{t-1} + \sum_{n=1}^{q_5} \Upsilon_6 \Delta LNRQ_{t-1} + \Psi_1 LNCO2_{t-1} + \Psi_2 LNGDP_{t-1} + \Psi_3 LNRENEWB_{t-1} + \Psi_4 LNFOSSIL_{t-1} + \Psi_5 LNGLOBA_{t-1} + \Psi_6 LNRQ_{t-1} + \mu t \quad (8)$$

The advantage of equation (8) over the model of Engle and Granger (1987) is that it allows us to estimate the short- and long-term effects. Equation (8) is comparable to the approach taken by Granger & Engle (1987). According to equation (8), α_0 denotes the intercept, the model's coefficients for each short-term variable are represented by $\Upsilon_{1-}\ \Upsilon_6$ parameters, and the corresponding long-term variable's coefficients are represented by $\Psi_1 - \Psi_6$ parameters, while μ_t is the error term. The long-run variable coefficients ($LNCO2_{t-1}$, $LNGDP_{t-1}$, $LNREWB_{t-1}$, $LNFOSSIL_{t-1}$, $LNGLOBA_{t-1}$, *and* $LNRQ_{t-1}$,) must be constant so that the null hypothesis can be investigated, according to Pesaran et al. (2001). Additionally, equation 9 contains a group for an error correcting model of the equations.

ECM:

$$\Delta LNCO2_t = \alpha_0 + \sum_{n=1}^{p} \Upsilon_1 \Delta LNCO2_{t-1} + \sum_{n=1}^{q_1} \Upsilon_2 \Delta LNGDP_{t-1} + \sum_{n=1}^{q_2} \Upsilon_3 \Delta LNRENEWB_{t-1} + \sum_{n=1}^{q_3} \Upsilon_4 \Delta LNFOSSIL_{t-1} + \sum_{n=1}^{q_4} \Upsilon_5 \Delta LNGLOBA_{t-1} + \sum_{n=1}^{q_4} \Upsilon_6 \Delta LNRQ_{t-1} + \Psi\ Z_{t-1} + \mu_t \quad (9)$$

Equation (9) has $\Psi\ Z_{t-1}$ as the coefficient for the error correction model, or ECM. As it gauges the speed at which our model approaches equilibrium, a significant and negative result is anticipated.

Table 5 The outcomes of the cointegration boundaries test.

Lags (AIC)	F-statstics	Outcome
1	17.84	Co-integration
	Lower limit at 1%= 3.41	Upper limit at 1% = 3.35
	Lower limit at 5% = 2.62	Upper limit at 5% = 3.79
	Lower limit at 10% = 3.41	Upper limit at 10% = 4.68

Source: E-views 12 and Authors' Compilation

The aforementioned bound test results in the production of two sets of essential numbers: lower and upper limit values. If F value is less than the lower limit, it is impossible to rule out the null hypothesis that cointegration does not exist. If the value of the F statistic (17.84) produced by the bounds testing, as seen in table 5, exceeds the upper limit critical value, then a long-run cointegration connection occurs.

Table 6 ARDL Long-run Form

	Coefficient	t-stat	Probability
LNGDP	0.581424	3.649011	0.0014
LNREWB	-0.059178	-13.54360	0.0000
LNFOSSIL	0.546315	7.292126	0.0000
LNGLOBA	-0.096988	-1.078703	0.2924
LNRQ	-0.076411	-1.613705	0.1208

Note: Statistically significant levels of rejection at 1% and 5% respectively, are indicated by the asterisks (***) and (**).

In table 6 above, the ARDL long-run coefficients are displayed. The outcome indicate that GDP and carbon dioxide (CO_2) emissions interact positively and significantly. This shows that, 1% increase in GDP increases CO2 by 0.58%, implying that as GDP increases, environmental degradation also increases in Japan. There is an expected strong and negative correlation between using renewable energy and CO_2. According to the finding, using 1% more of renewable energy results in a 0.06% decrease in CO_2 emissions, which helps in improving environmental sustainability in Japan. Furthermore, we find that, statistically speaking, the usage of fossil fuels has an expectedly positive and strong connection with CO_2.This implies 1% rise in fossil fuel consumption rises CO_2 emissions by 0.55% which reduces the environmental quality. While globalization and regulatory quality have both long-term negative and inconsequential connection with CO_2.

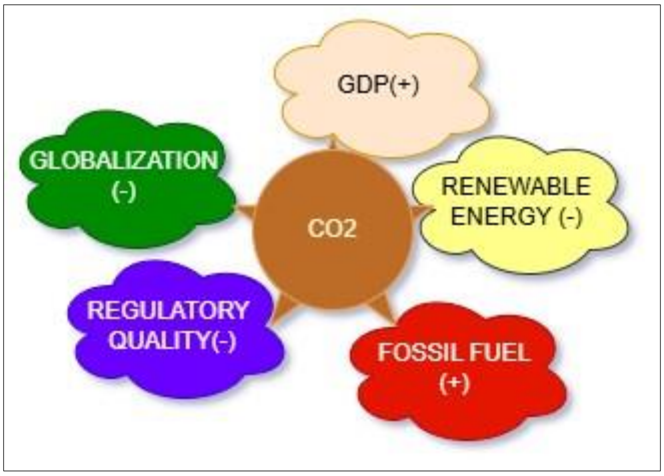

Figure 3 The long-term relationships between CO_2 and GDP (+), renewable energy usage (-), fossil fuel (+), regulatory quality (-) and globalization (-)

Table 7 ECM Regression result

Variable	Coefficient	Std-Error	t-Statistics	Prob.
C	7.203107	0.628746	11.45631	0.0000
D(LNGDP)	0.847366	0.111730	7.584021	0.0000
D(LNRQ)	0.103955	0.057934	1.794362	0.0865
CointEq(-1)*	-0.978000	0.094044	-11.46271	0.0000

Table 7 above's short-run results demonstrate that, with the exception of regulatory quality, all the other variables were statistically significant. The significance level was set at 5%, the variables converge over the long term with a statistically significant equilibrium speed of -0.97, or at 97%. Due to the positive correlation between GDP and CO_2, a 1% rise in GDP will lead to 0.85% increase in CO_2, implying an increase in the environmental degradation.

4.4. Diagnostic Test

The stability of the model is often assessed using a variety of diagnostic tests. The three tests in Table 8 below were applied to our paper, and the expectations for linear regression were verified. According to the findings in Table 8, the model's residuals were devoid of serial correlation and heteroskedasticity, and are normally distributed. Figures 4 and 5 depict the model's stability structure using cumulative sums and cumulative sums of squares (CUSUMSQ and CUSUM, respectively). The middle lines show that, at a 5% level of significance, coefficients are constant.

Table 8 Residual Diagnostic Test

Diagnostic Statistics	Prob. values	Outcome
LM test	0.9818	No serial correlation
Breusch–Pagan–Godfrey	0.1085	No heteroskedasticity
Jarque–Bera Test	0.9284	Normal

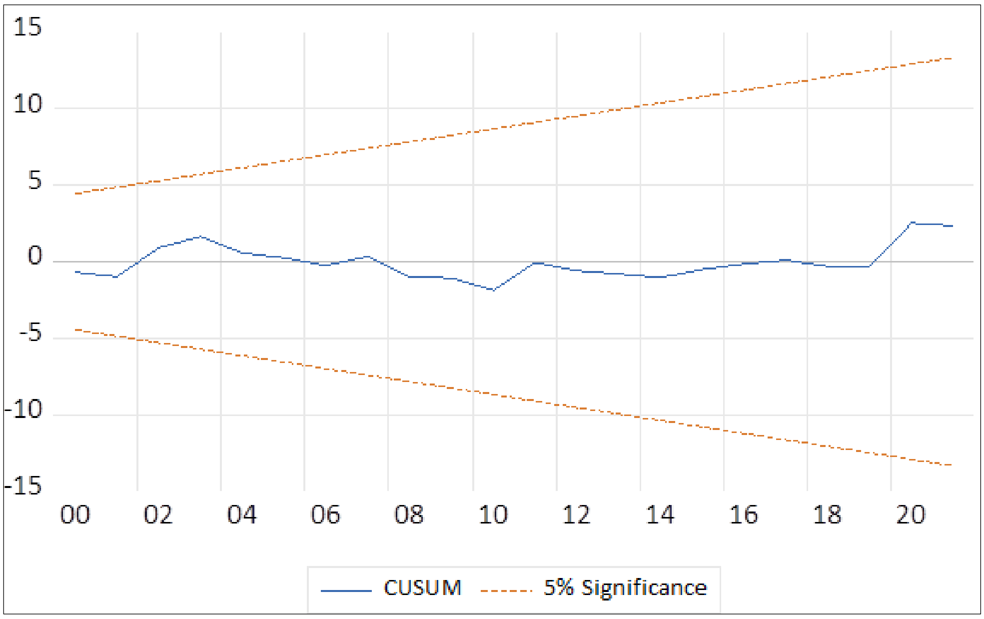

Figure 4 Cusum

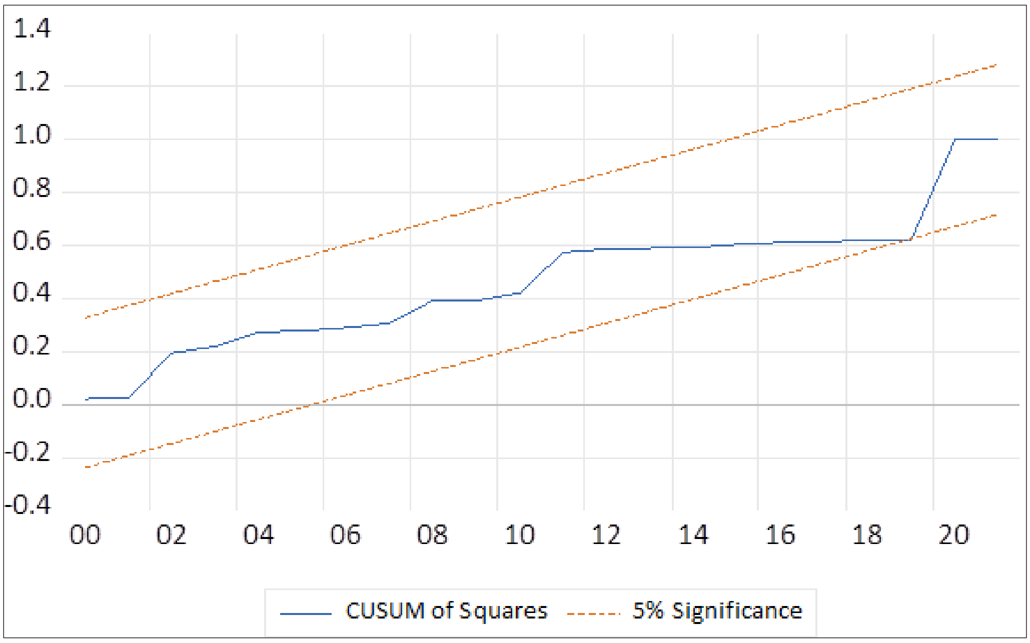

Figure 5 Cusum of Squares

4.5. Model Robustness

In the long-run model, GDP, usage of fossil fuels and renewable energy were statistically significant as indicated in table 9. GDP and use of fossil fuels had a positive co-efficient while use of renewable energy had a negative co-efficient. The fact that the results obtained using the FMOLS, DOLS and CCR models in Table 9 are similar and shows how robust the model is (Phillips & Hansen, 1990). Only regulatory quality is statistically insignificant in all three models, with GDP and fossil fuels statistically significant but having a positive coefficient while renewable energy statistically significant with a negative coefficient. Finally, the FMOLS, DOLS, and CCR models verified the ARDL long-run model as shown in table 9 below.

Table 9 Alternative Outcome

FMOLS			**DOLS**			**CCR**		
Variable	Coeff.	Prob	Variable	Coeff.	Prob.	Variable	Coeff.	Prob.
LNGDP	0.836	0.000	LNGDP	1.174	0.021	LNGDP	0.840	0.000
LNRENWB	-0.063	0.000	LNRENWB	-0.065	0.000	LNRENWB	-0.063	0.000
LNFOSSIL	0.568	0.000	LNFOSSIL	0.658	0.005	LNFOSSIL	0.572	0.000
LNGLOBA	-0.191	0.006	LNGLOBA	-0.467	0.153	LNGLOBA	-0.199	0.011
LNRQ	-0.029	0.455	LNRQ	-0.116	0.206	LNRQ	-0.030	0.454
C	4.053	0.001	C	1.870	0.614	C	4.038	0.005
R^2	0.86		R^2	0.96		R^2	0.88	

Table 10 The Optimal Lag Selection

Lag 1	**LogL**	**LR**	**FPE**	**AIC**	**SC**	**HQ**
0	263.8651	NA	1.38e-15	-17.19101	-16.91077	-17.10136
1	395.3480	201.6070*	2.50e-1*	-23.55653*	-21.59486*	-22.92898*
2	431.1206	40.54230	3.48e-18	-23.54137	-19.89826	-22.37591

The duration of the lag in ARDL is critical since it helps to offer an accurate estimate. The method is used in the research for this reason. The results of the optimal lag selection which is shown in table 10, aims to establish the best criteria for lag duration selection, show that, and lag 1 is the best latency to use as shown in table 10. The criteria with the lowest score, the Akaike information criterion (AIC), was then chosen.

Table 11 Pearson Correlation matrix

Correlation t-statistics Probability	LNCO2	LNGDP	LNRENEWB	LNFOSSIL	LNGLOBA	LNRQ
LNCO2	1.0000					
	0.203559	1.0000				
LNGDP	1.138781					
	0.2638					
	-0.364742	0.751449	1.0000			
RENEWB	-2.145584	6.238116				
	0.0401	0.0000				
	0.042313	0.723434	0.840297	1.0000		
LNFOSSIL	0.231965	5.739346	8.489714			
	0.8181	0.0000	0.0000			
	0.252500	0.946411	0.650074	0.672835	1.0000	
LNGLOBA	1.429312	16.05037	4.685803	4.981491		
	0.1632	0.0000	0.0001	0.0000		
LNRQ	-0.307015	-0.842036	-0.613730	-0.722263	-0.852894	1.0000
	-1.766922	-8.549953	-4.257721	-5.719918	-8.947761	
	0.0874	0.0000	0.0002	0.0000	0.0000	

The computed Pearson correlation coefficients for every pair of variables are shown in the table. The p value shows the marginal probability, and the t-statistics show the significance of the correlation coefficient.

The measurement of a monotonic relationship between two variables is called correlation. When two variables have a monotonic connection, either (1) the other variable's value rises in proportion to the value of the first variable; or (2) The value of the other variable falls as the value of the first variable rises Lee & Nicewander (1988). Translating the correlation coefficient into descriptors such as "strong," "moderate," or "weak" association has been proposed in a number of ways. It is best to utilize these cutoff criteria sparingly because they are arbitrary and inconsistent. It is debatable whether values fall between 0.1 and 0.9, even though most scholars would likely agree that the former denotes a very strong relationship and the latter a negligible one. For instance, depending on the applicable rule of thumb, a correlation coefficient of 0.65 could be viewed as either "good" or "moderate." When there is a perfect correlation of –1 or +1, every data point falls perfectly on the straight line.

The Pearson correlation in table 11 indicates that, the relationship between CO_2 and GDP is a weak positive correlation, meaning that increase in GDP increases CO_2 because the coefficient is 0.20. Similarly, fossil fuels and globalization both have positive and weak relationship with CO_2, with 0.04 and 0.25 coefficients respectively. However, renewable energy and regulatory quality both have negative and weak correlation with CO_2, with coefficients of -0.36 and -0.31 respectively. Meaning increase in both renewable energy use and regulatory quality reduces CO_2 by implication improvement on environmental sustainability in Japan.

On the other hand, renewable energy use, fossil fuel and globalization all have positive and strong correlation with GDP, with coefficient values of 0.75, 0.72 and 0.94 respectively. This indicates that increase in renewable energy consumption, fossil fuel and globalization will lead to increase in GDP. While regulatory quality has a negative and very strong correlation with GDP, with coefficient of 0.94. Meaning increase in regulatory quality reduces GDP. Fossil fuel and globalization have strong and positive connection with renewable energy, with correlation coefficient of 0.84 and 0.65 respectively while regulatory quality has a negative and moderate correlation coefficient of -0.61 with renewable energy use. Furthermore, Globalization has a positive and moderate relationship with fossil fuel with coefficient of 0.67 while regulatory quality has a negative and strong relationship with fossil fuel with coefficient of -0.72. Finally, globalization and regulatory quality have negative and strong correlation between them with coefficient of -0.85, meaning increase in regulatory quality will certainly reduce globalization.

5. Discussions of findings

With the motivation that all the variables are integrated of order I (0) and I (1), our research goal was to examine the correlations between CO_2 and Japan's economic growth, the usage of renewable energy, using fossil fuels, globalization index, and regulatory quality. For a short-term relationship, a model for error correction was created, and long-run cointegration was assessed using ARDL model from a yearly data of 1990 to 2021. The empirical findings from boundaries test in table 4 demonstrated that the F-Statistics of 17.84 is higher than the lower and upper limits critical values and robustness check must be performed to verify the ARDL limits test results.

The ARDL long-term coefficients are displayed. The data shows a positive and significant relationship, relating GDP to CO_2. Meaning that, increase in GDP increases CO_2 and by implication increases long-run environmental degradation in Japan. This outcomes in consistent with a research based on data gathered from 138 countries between 1971 and 2007 which was presented by Wang (2013), also in consistent with the findings of (Damak & Ewaede 2024; Ochanya & Damak 2025). The conclusion implies that carbon dioxide emissions can be explained by national incomes. The eventual increase in national GDP will translate into an increase in carbon dioxide emissions. In nearly 80% of the countries, the drive for economic expansion has led to a rise in carbon dioxide emissions. Although there is an expected and significant link between the use of renewable energy and CO_2. The relationship between renewable energy usage and CO_2 is negative, according to this, using more renewable energy leads to 0.06 percent decrease in CO_2, which helps the environment in Japan. This demonstrates how a rise in Japan's usage of renewable energy helps to slow down environmental deterioration. A significant portion of Japan's primary energy consumption can be attributed to the connection between CO_2 and renewable energy utilization. According to a study by (Kirikkaleli & Adebayo 2021) carried in India, utilizing green energy has a negative impact on CO_2 while using clean energy increases the sustainability of the environment. The results are in line with that study similar to this, Adebayo, & Rjoub (2021) analyzed the connection between CO_2 and green energy use in Argentina using a dataset created with the NARDL approach that covers the years 1990–2018. According to their findings, while utilizing more green energy reduces CO_2 emissions, using less green energy results in a worsening of Argentina's environmental damage. The results of Bilgili et al. (2016) and Damak & Hasan (2023) demonstrated that using green energy helps lower CO_2 emissions by implying enhancing environmental quality. They used data from 1977 to 2010 and the DOLS and FMOLS methodologies in order to evaluate the connection between CO_2 emissions and the utilization of renewable energy. The finding also concurs with earlier research by Ben Jebli, & Ben Youssef (2017), renewable energy is slowing the pace of CO_2 in Tunisia.

Fossil fuel consumption, shows a strong and positive association between fossil fuel and CO_2. It is assumed that higher fossil fuel usage will expedite environmental deterioration in Japan or increase CO_2 emissions both in the short and long-run. Our findings are in agreement with those of Ramzan et al. (2022), who examined how Pakistan ecological imprint changed between 1960 and 2019 because of the openness to trade. The outcomes show that economic growth, openness to trade, and fossil fuel use all hasten environmental damage. In the same way, Aslam et al. (2021) for Malaysia utilized data from 1971 to 2016 and the ARDL model, and they asserted that the usage of fossil fuels, trade openings, and economic expansion all exacerbate CO_2.

6. Conclusion

Our analysis emphasizes the connection between economic growth, energy usage, globalization, and regulatory quality on CO_2 emissions utilizing yearly data for Japan from 1990 to 2021. Applying the ARDL technique is motivated by the fact that every variable is integrated of order zero I (0) and I (1), using the ADF and PP test. The ARDL limits F-test demonstrate a long-run association between CO_2, GDP, renewable energy, fossil fuels, globalization, and regulatory quality at a significance level of 5%. The outcome of the estimation of the long-run coefficients proved that while the GDP and CO_2 have a favorable and significant association, meaning increase in GDP increases CO_2 in both short and long-run period in Japan. There is a strong negative correlation between CO_2 emissions and the utilization of renewable energy, suggesting that using green energy more frequently will improve environmental sustainability in Japan. Additionally, the predicted ECT coefficients are statistically significant negative values which is the quickness of adjustment to reach long-term balance. The research' results demonstrate that, with a positively and statistically significant sign for the coefficient of fossil fuel consumption, environmental deterioration in Japan is projected to worsen as fossil fuel consumption rises. Furthermore, regulatory quality has a negative and insignificant coefficient, whereas the globalization index has a negative and insignificant coefficient in the long-term. FMOLS, DOLS, and CCR are used to calculate the long-term elasticities for the relevant association between the variables, demonstrating the robustness of the results from the ARDL cointegration.

6.1. Suggested Policy

According to the study's empirical findings, sustainable development and cleaner growth are highly valued in Japan's long-term economic objectives. On the other hand, environmental degradation may make it more challenging to meet sustainable development objectives. Japan should thus begin raising public awareness, implement the necessary structural changes to enable income levels to increase without raising emissions, and endeavor to lessen its dependency on fossil fuels in order to reduce pollution. Overall, our study supports the findings of earlier research and suggests that renewable energy sources could be used as a policy instrument to lessen pollution and environmental harm.

We can offer some perceptive suggestions for a more sustainable and ecologically friendly environment based on the factual facts for Japan described above. A cleaner, greener environment and increased energy efficiency are two UN Sustainable Development Goals that Japan may be able to accomplish with the help of these policy implications. According to the study's findings, governments should enforce stringent laws, promote investments in renewable energy sources, and discourage the use of fossil fuels in order to lower environmental degradation. This is because people's quality of life is improved when they employ renewable energy sources. Converting extra energy from economic growth into renewable energy sources, which requires a technology shift, is an efficient way to reduce CO_2.

6.2. Limitation

A limitation regarding this study is that it does not account for trade openness, urbanization, foreign direct investment, or other factors that contribute to environmental degradation. Instead, it is an empirical investigation that is subjective regarding the effects of energy use, economic growth, globalization, and regulatory quality on CO_2 emissions. In order to evaluate these relationships, future research should also make use of additional environmental degradation proxies, such as ecological footprint, load factor, and consumption-based carbon emissions. Finally, a significant limitation of this investigation is the inaccessibility of data after the designated time frame.

Compliance with ethical standards

Disclosure of conflict of interest

No conflict of interest to be disclosed.

References

[1] Addai, K., Serener, B., & Kirikkaleli, D. (2023). Environmental sustainability and regulatory quality in emerging economies: Empirical evidence from Eastern European Region. *Journal of the Knowledge Economy*, *14*(3), 3290-3326.

[2] Adebayo, T. S., & Kirikkaleli, D. (2021). Impact of renewable energy consumption, globalization, and technological innovation on environmental degradation in Japan: application of wavelet tools. *Environment, Development and Sustainability*, *23*(11), 16057-16082.

[3] Adebayo, T. S., & Rjoub, H. (2021). A new perspective into the impact of renewable and nonrenewable energy consumption on environmental degradation in Argentina: a time–frequency analysis. *Environmental Science and Pollution Research*, 1-17.

[4] Ajii, O., & Damak, O. I. (2025). Exploring the Dynamics of Poverty, Public-Private Partnerships on Nigeria's Environmental Sustainability. *Sustainable Development*.

[5] Akbostancı, E., Türüt-Aşık, S., & Tunç, G. İ. (2009). The relationship between income and environment in Turkey: is there an environmental Kuznets curve?. *Energy policy*, *37*(3), 861-867.

[6] Andrew, R. M. (2020). A comparison of estimates of global carbon dioxide emissions from fossil carbon sources. *Earth System Science Data*, *12*(2), 1437-1465.

[7] Apergis, N., & Payne, J. E. (2011). The renewable energy consumption–growth nexus in Central America. *Applied Energy*, *88*(1), 343-347.

[8] Apergis, N., Payne, J. E., Menyah, K., & Wolde-Rufael, Y. (2010). On the causal dynamics between emissions, nuclear energy, renewable energy, and economic growth. *Ecological Economics*, *69*(11), 2255-2260.

[9] Aslam, S., Herodotou, H., Mohsin, S. M., Javaid, N., Ashraf, N., & Aslam, S. (2021). A survey on deep learning methods for power load and renewable energy forecasting in smart microgrids. *Renewable and Sustainable Energy Reviews*, *144*, 110992.

[10] Baiocchi, Giovanni, and Jan C. Minx. "Understanding changes in the UK's CO2 emissions: A global perspective." (2010): 1177-1184.

[11] Bardi, W., & Hfaiedh, M. A. (2021). Causal interaction between FDI, corruption and environmental quality in the MENA region. *Economies*, *9*(1), 14.

[12] Bélaïd, F., & Youssef, M. (2017). Environmental degradation, renewable and non-renewable electricity consumption, and economic growth: Assessing the evidence from Algeria. *Energy policy*, *102*, 277-287.

[13] Ben Jebli, M., & Ben Youssef, S. (2017). Renewable energy consumption and agriculture: evidence for cointegration and Granger causality for Tunisian economy. *International Journal of Sustainable Development & World Ecology*, *24*(2), 149-158.

[14] Berrone, P., & Gomez-Mejia, L. R. (2009). Environmental performance and executive compensation: An integrated agency-institutional perspective. *Academy of Management Journal*, *52*(1), 103-126.

[15] Bilgili, F., Koçak, E., & Bulut, Ü. (2016). The dynamic impact of renewable energy consumption on CO2 emissions: a revisited Environmental Kuznets Curve approach. *Renewable and Sustainable Energy Reviews*, *54*, 838-845.

[16] Bunea, A., & Chrisp, J. (2023). Reconciling participatory and evidence-based policymaking in the EU Better Regulation policy: mission (im) possible?. *Journal of European Integration*, *45*(5), 729-750.

[17] Chams, N., & García-Blandón, J. (2019). On the importance of sustainable human resource management for the adoption of sustainable development goals. *Resources, Conservation and Recycling*, *141*, 109-122.

[18] Chen, Y., Wang, Z., & Zhong, Z. (2019). CO2 emissions, economic growth, renewable and non-renewable energy production and foreign trade in China. *Renewable energy*, *131*, 208-216.

[19] Damak, O. I., & Eweade, B. S. (2024). Do economic growth, the legal system, and energy consumption lessen the ecological footprint? Evidence from South Korea. *Energy & Environment*, 0958305X241270280.

[20] Damak, O. I., & Güngör, H. (2023). Globalization and energy consumption's effect on Japan's ecological imprint: Implications for environmental sustainability. *Sustainable Development*.

[21] Damak, O. I., & Güngör, H. (2024). The effects of rule of law, regulatory quality, and R&D on Japan's environmental sustainability. *Sustainable Development*, *33*(2), 2278-2291.

[22] Dauvergne, C. (2008). *Making people illegal: What globalization means for migration and law*. Cambridge University Press.

[23] Delmas, M. A., Lyon, T. P., & Maxwell, J. W. (2019). Understanding the role of the corporation in sustainability transitions. *Organization & Environment*, *32*(2), 87-97.

[24] Delmas, M., & Toffel, M. W. (2004). Stakeholders and environmental management practices: an institutional framework. *Business strategy and the Environment*, *13*(4), 209-222.

[25] Dinda, S. (2004). Environmental Kuznets curve hypothesis: a survey. *Ecological economics*, *49*(4), 431-455.

[26] Dogan, B., & Deger, O. (2016). How globalization and economic growth affect energy consumption: Panel data analysis in the sample of BRIC countries. *International Journal of Energy Economics and Policy*, *6*(4), 806-813.

[27] Dogan, E., & Turkekul, B. (2016). CO 2 emissions, real output, energy consumption, trade, urbanization and financial development: testing the EKC hypothesis for the USA. *Environmental Science and Pollution Research*, *23*, 1203-1213.

[28] Dong, K., Hochman, G., & Timilsina, G. R. (2018). Are driving forces of CO2 emissions different across countries?: insights from identity and econometric analyses. *Insights from Identity and Econometric Analyses (June 19, 2018). World Bank Policy Research Working Paper*, (8477).

[29] Dong, K., Hochman, G., & Timilsina, G. R. (2020). Do drivers of CO2 emission growth alter overtime and by the stage of economic development?. *Energy Policy*, *140*, 111420.

[30] Dreher, A. (2006). Does globalization affect growth? Evidence from a new index of globalization. *Applied economics*, *38*(10), 1091-1110.

[31] Engle, R. F., & Granger, C. W. (1987). Co-integration and error correction: representation, estimation, and testing. *Econometrica: journal of the Econometric Society*, 251-276.

[32] Engle, R. F., & Granger, C. W. (1987). Co-integration and error correction: representation, estimation, and testing. *Econometrica: journal of the Econometric Society*, 251-276.

[33] Engle, R. F., & Granger, C. W. (1987). Co-integration and error correction: representation, estimation, and testing. *Econometrica: journal of the Econometric Society*, 251-276.

[34] Ertugrul, H. M., Cetin, M., Seker, F., & Dogan, E. (2016). The impact of trade openness on global carbon dioxide emissions: Evidence from the top ten emitters among developing countries. *Ecological Indicators*, *67*, 543-555.

[35] Farhani, S. (2013). Renewable energy consumption, economic growth and CO2 emissions: Evidence from selected MENA countries. *Energy Economics Letters*, *1*(2), 24-41.

[36] Grossman, G. M., & Krueger, A. B. (1991). Environmental impacts of a North American free trade agreement.

[37] Huang, W. M., Lee, G. W., & Wu, C. C. (2008). GHG emissions, GDP growth and the Kyoto Protocol: A revisit of Environmental Kuznets Curve hypothesis. *Energy Policy*, *36*(1), 239-247.

[38] Jin, T. (2022). The evolutionary renewable energy and mitigation impact in OECD countries. *Renewable Energy*, *189*, 570-586.

[39] Johansen, S. (1988). Statistical analysis of cointegration vectors. *Journal of economic dynamics and control*, *12*(2-3), 231-254.

[40] Johansen, S., & Juselius, K. (1990). Maximum likelihood estimation and inference on cointegration—with appucations to the demand for money. *Oxford Bulletin of Economics and statistics*, *52*(2), 169-210.

[41] Johansen, S., & Juselius, K. (1990). Maximum likelihood estimation and inference on cointegration—with appucations to the demand for money. *Oxford Bulletin of Economics and statistics*, *52*(2), 169-210.

[42] Johansen, S., & Juselius, K. (1990). Maximum likelihood estimation and inference on cointegration—with appucations to the demand for money. *Oxford Bulletin of Economics and statistics*, *52*(2), 169-210.

[43] Jordan, S., & Philips, A. Q. (2018). Cointegration testing and dynamic simulations of autoregressive distributed lag models. *The Stata Journal*, *18*(4), 902-923.

[44] Kahia, M., Aïssa, M. S. B., & Lanouar, C. (2017). Renewable and non-renewable energy use-economic growth nexus: The case of MENA Net Oil Importing Countries. *Renewable and Sustainable Energy Reviews*, *71*, 127-140.

[45] Khan, I., & Hou, F. (2021). The dynamic links among energy consumption, tourism growth, and the ecological footprint: the role of environmental quality in 38 IEA countries. *Environmental Science and Pollution Research*, *28*, 5049-5062.

[46] Khan, S. A. R., Yu, Z., Belhadi, A., & Mardani, A. (2020). Investigating the effects of renewable energy on international trade and environmental quality. *Journal of Environmental management*, *272*, 111089.

[47] Khanna, M., & Anton, W. R. Q. (2002). Corporate environmental management: regulatory and market-based incentives. *Land economics*, *78*(4), 539-558.

[48] Kirikkaleli, D., & Adebayo, T. S. (2021). Do renewable energy consumption and financial development matter for environmental sustainability? New global evidence. *Sustainable Development*, *29*(4), 583-594.

[49] Klees, S. J., Ginsburg, M., Anwar, H., Robbins, M. B., Bloom, H., Busacca, C., ... & Reedy, T. D. (2020). The World Bank's SABER: A critical analysis. *Comparative Education Review*, *64*(1), 46-65.

[50] Kuznets, S. (1955). International differences in capital formation and financing. In *Capital formation and economic growth* (pp. 19-111). Princeton University Press.

[51] Lean, H. H., & Smyth, R. (2010). CO2 emissions, electricity consumption and output in ASEAN. *Applied energy*, *87*(6), 1858-1864.

[52] Lee Rodgers, J., & Nicewander, W. A. (1988). Thirteen ways to look at the correlation coefficient. *The American Statistician*, *42*(1), 59-66.

[53] Lopez, R. (2017). The environment as a factor of production: The effects of economic growth and trade liberalization 1. In *International trade and the environment* (pp. 239-260). Routledge.

[54] Moutinho, V., & Robaina, M. (2016). Is the share of renewable energy sources determining the CO2 kWh and income relation in electricity generation?. *Renewable and Sustainable Energy Reviews*, *65*, 902-914.

[55] Nelson, C. R., & Plosser, C. R. (1982). Trends and random walks in macroeconmic time series: some evidence and implications. *Journal of monetary economics*, *10*(2), 139-162.

[56] Oh, W., & Lee, K. (2004). Energy consumption and economic growth in Korea: testing the causality relation. *Journal of policy modeling*, *26*(8-9), 973-981.

[57] Oliver, C. (1991). Strategic responses to institutional processes. *Academy of management review*, *16*(1), 145-179.

[58] Pesaran, M. H., Shin, Y., & Smith, R. J. (2001). Bounds testing approaches to the analysis of level relationships. *Journal of applied econometrics*, *16*(3), 289-326.

[59] Pesaran, M. H., Shin, Y., & Smith, R. J. (2001). Bounds testing approaches to the analysis of level relationships. *Journal of applied econometrics*, *16*(3), 289-326.

[60] Phillips, P. C., & Hansen, B. E. (1990). Statistical inference in instrumental variables regression with I (1) processes. *The review of economic studies*, *57*(1), 99-125.

[61] Portugal-Pereira, J., & Esteban, M. (2014). Implications of paradigm shift in Japan's electricity security of supply: A multi-dimensional indicator assessment. *Applied Energy*, *123*, 424-434.

[62] Rahman, M. M., & Kashem, M. A. (2017). Carbon emissions, energy consumption and industrial growth in Bangladesh: Empirical evidence from ARDL cointegration and Granger causality analysis. *Energy policy*, *110*, 600-608.

[63] Ramzan, M., Raza, S. A., Usman, M., Sharma, G. D., & Iqbal, H. A. (2022). Environmental cost of non-renewable energy and economic progress: do ICT and financial development mitigate some burden?. *Journal of Cleaner Production*, *333*, 130066.

[64] Romanello, M., Di Napoli, C., Drummond, P., Green, C., Kennard, H., Lampard, P., ... & Costello, A. (2022). The 2022 report of the Lancet Countdown on health and climate change: health at the mercy of fossil fuels. *The Lancet*, *400*(10363), 1619-1654.

[65] Romanello, M., McGushin, A., Di Napoli, C., Drummond, P., Hughes, N., Jamart, L., ... & Hamilton, I. (2021). The 2021 report of the Lancet Countdown on health and climate change: code red for a healthy future. *The Lancet*, *398*(10311), 1619-1662.

[66] Shahbaz, M., Khan, S., & Tahir, M. I. (2013). The dynamic links between energy consumption, economic growth, financial development and trade in China: fresh evidence from multivariate framework analysis. *Energy economics*, *40*, 8-21.

[67] Shahbaz, M., Shahzad, S. J. H., Ahmad, N., & Alam, S. (2016). Financial development and environmental quality: the way forward. *Energy policy*, *98*, 353-364.

[68] Shahbaz, M., Van Hoang, T. H., Mahalik, M. K., & Roubaud, D. (2017). Energy consumption, financial development and economic growth in India: New evidence from a nonlinear and asymmetric analysis. *Energy Economics*, *63*, 199-212.

[69] Sharif, A., Baris-Tuzemen, O., Uzuner, G., Ozturk, I., & Sinha, A. (2020). Revisiting the role of renewable and non-renewable energy consumption on Turkey's ecological footprint: Evidence from Quantile ARDL approach. *Sustainable cities and society*, *57*, 102138.

[70] Siebenhüner, B., & Arnold, M. (2007). Organizational learning to manage sustainable development. *Business strategy and the environment*, *16*(5), 339-353.

[71] Soytas, U., & Sari, R. (2009). Energy consumption, economic growth, and carbon emissions: challenges faced by an EU candidate member. *Ecological economics*, *68*(6), 1667-1675.

[72] Stock, J. H., & Watson, M. W. (1993). A simple estimator of cointegrating vectors in higher order integrated systems. *Econometrica: journal of the Econometric Society*, 783-820.

[73] Sun, Q. Y., & Yu, L. (2012). Research on low-carbon eco-city construction in china from the perspective of ecological ethics. *Advanced Materials Research*, *573*, 684-689.

[74] Tatoglu, E., Frynas, J. G., Bayraktar, E., Demirbag, M., Sahadev, S., Doh, J., & Koh, S. L. (2020). Why do emerging market firms engage in voluntary environmental management practices? A strategic choice perspective. *British Journal of Management*, *31*(1), 80-100.

[75] Tissot, A., Croisier, J., Pietrantuono, G., Baier, A., Ninke, L., Rother, N., & Babka von Gostomski, C. (2019). Zwischenbericht I zum Forschungsprojekt" Evaluation der Integrationskurse (EvIk)": erste Analysen und Erkenntnisse.

[76] Udeagha, M. C., & Muchapondwa, E. (2022). Investigating the moderating role of economic policy uncertainty in environmental Kuznets curve for South Africa: Evidence from the novel dynamic ARDL simulations approach. *Environmental Science and Pollution Research*, *29*(51), 77199-77237.

[77] Usman, M., Jahanger, A., Makhdum, M. S. A., Balsalobre-Lorente, D., & Bashir, A. (2022). How do financial development, energy consumption, natural resources, and globalization affect Arctic countries' economic growth and environmental quality? An advanced panel data simulation. *Energy*, *241*, 122515.

[78] Van Marrewijk, M., & Hardjono, T. W. (2003). European corporate sustainability framework for managing complexity and corporate transformation. *Journal of business ethics*, *44*, 121-132.

[79] Vanham, D., Leip, A., Galli, A., Kastner, T., Bruckner, M., Uwizeye, A., ... & Hoekstra, A. Y. (2019). Environmental footprint family to address local to planetary sustainability and deliver on the SDGs. *Science of the Total Environment*, *693*, 133642.

[80] Wang, Y., Yao, L., Wang, L., Liu, Z., Ji, D., Tang, G., ... & Xin, J. (2014). Mechanism for the formation of the January 2013 heavy haze pollution episode over central and eastern China. *Science China Earth Sciences*, *57*, 14-25.

[81] Zapata, M. J., Hall, C. M., Lindo, P., & Vanderschaeghe, M. (2013). Can community-based tourism contribute to development and poverty alleviation? Lessons from Nicaragua. In *Tourism and the Millennium Development Goals* (pp. 98-122). Routledge.

[82] Zhang, X., & Wang, Y. (2017). How to reduce household carbon emissions: A review of experience and policy design considerations. *Energy Policy*, *102*, 116-124.

[83] Zhongming, Z., Linong, L., Xiaona, Y., Wangqiang, Z., & Wei, L. (2018). Ministry of Education, Culture, Sports, Science and Technology (MEXT) Japan [23651142].

[84] Zoundi, Z. (2017). CO2 emissions, renewable energy and the Environmental Kuznets Curve, a panel cointegration approach. *Renewable and Sustainable Energy Reviews*, *72*, 1067-1075.