Pollution 2021, 7(2): 275-291
DOI: 10.22059/poll.2020.312886.925

RESEARCH PAPER

Do Technological Innovation and Renewable Energy Consumption in Japan Important for Consumption-based Carbon Emissions?

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Received: 31 October 2020, Revised: 22 December 2020, Accepted: 04 March 2021

ABSTRACT
With growing global warming issues, the association between technological innovation and environmental pollution has created significant debate in recent years. This paper examines the long-run and causal impact of technological innovation, economic growth, and renewable energy on consumption-based carbon emissions in Japan. The study utilized quarterly data spanning between 1990 and 2015. The study utilized recent econometrics techniques such as Maki co-integration, ARDL bunds test, FMOLS, DOLS, and frequency domain causality techniques. To the author's understanding, no prior studies have been conducted in Japan using consumption-based carbon emissions as a proxy of environmental degradation. Thus, this empirical analysis contributes to the literature. The findings from the ARDL bounds and Maki co-integration tests revealed evidence of co-integration among the series. The results of FMOLS and DOLS reveal that both renewable energy and technological innovation improve the environmental quality, while economic growth harms the quality of the environment. The results of the frequency-domain causality technique reveal that technological innovation, renewable energy, and economic growth can significantly predict consumption-based carbon emissions in Japan. Based on these outcomes, we suggested that Japan's government should be careful when formulating policies that trigger growth, which will have a detrimental impact on the environmental quality. Our empirical outcome also revealed that any policy that encourages renewable energy should be encouraged since it enhances environmental quality.

KEYWORDS: Consumption-Based Carbon Emissions, Economic Growth, Renewable Energy Consumption, Technological Innovation, Japan.

INTRODUCTION

Environmental degradation is one of the major concerns facing the contemporary world, and it has gained a plethora of attention over the last decade because of its linkage with humans and global warming. Several studies have asserted that greenhouse gasses (GHG_S) contribute

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to global warming (Destek and Sarkodie, 2019; Algunaibet et al., 2019; Khan et al., 2019; Atasoy 2017; Kulak et al., 2013). According to EIA (2019), the global land and ocean surface temperature in March 2020 was 1.16 ° C (2.09 ° F) above the 20th century average of 12.7°C (54.9°F) and the second-highest in the 141-year record. These emissions only contribute about 75% of GHGs, which have resulted in acute weather conditions and global climate change, including heat waves, heavy rains, floods, and droughts, over the last decade. Besides, Diffenbaugh (2020) stated that these emissions occurrences have a considerable effect on the ecosystem and primarily on human lives. Undoubtedly, many factors could reduce CO_2 emissions, but, in recent times, technological advances and renewable energy use have been considered the main determinants of CO_2 emissions (Ummealla et al. 2019; Shan et al. 2018). Japan is one of the largest electronics conglomerates globally, most cutting-edge inventions than any other Asian country. Similarly, Japan's population, which is about 126 million, is ranked the third-largest economy and second technological advanced country globally. Nevertheless, Japan is the 5th largest CO_2 emitter in the world (EIA 2019). Furthermore, its economy has witnessed a duration of speedy economic growth with an average annual growth of 1.3 % (2001-2007), a decline of 1.2% in the following quarter after the financial crisis, following an increase of 1.2% for the period of 2013-2017 (Lechevaliera and Monfort, 2017). It was reported that one of the most significant causes of sustained economic growth is the result of the ever-increasing level of urbanization and industrialization, and this development birthed the concentration of environmental pollutions (Yoro and Daramola, 2020).

To fix this environmental issue, Japan has set its own national greenhouse reduction goals for the post-2020 period. The existing Japan NDC target under the Paris Accord “Highly Insufficient”, as it is not harsh enough to restrain warming to 2°C, let alone 1.5˚C. If all nations were to follow approach of Japan, warming could reach over 3°C and up to 4°C (EIA, 2019). One of the government's steps to curb GHGs was to sign up to the Kyoto Protocol of 1997 and the Paris Climate Agreement of 2015. However, emission control has been an excellent challenge for environmentalists, policymakers, and researchers in Japan, which has led to the consideration of new and creative ways of dealing with environmental issues. Since the global meltdown of 2008-2009, new prospects for developing renewable energy have become the priority of many countries to improve their economies. Many developed countries rely on conventional energy sources such as coal, oil, and gas which are primarily responsible for pollution worldwide. Further, by adopting environmental management activities such as renewable energy and technological advancement can mitigate CO_2 emissions. As renewable energy technology (solar power, wind power, etc.) becomes more advanced, the cost of renewable energy can drop rapidly. Hence, technological innovation would have a significant impact on renewable energy consumption and global energy use pattern. Renewable energy is expected to minimize environmental degradation.

Renewable energy can produce the required energy for nations, thus eliminating the need for fossil fuel. Increased energy dependency leading to energy protection and market stability are further advantages of renewable energy (Kick, 2011), resulting in a massive rise in renewable energy in Japan, such as solar energy currently at 14.3 percent, wind power at 18.5 percent, biomass at 22.7 percent in 2019 (EIA, 2019). This study examines the use of technological innovation primarily as the world moves towards a paradigm shift in consumption and development that encourages better use of natural resources. Besides, the nation's capacity to meet current societies' natural resources demands without negatively impacting future generations is closely linked to sustainable growth. Song et al. (2019) argue that technological advances will help achieve sustainable development through productive and effective use of natural resources if adequately considered and given the utmost importance. Therefore, the world economies can meet the needs of the growing population by using modern technologies without further damaging the environmental quality. According to Bekun et al. (2019), environmentally friendly innovations, including recycling, reprocessing, and the implementation of advanced methods can help reduce the environment's degradation. Therefore, this study tends to explore the long run and causal impact of technological innovation, renewable energy, and economic growth on Japan’s Consumption-based carbon emissions.

With growing global warming issues, the association between technological innovation and CO_2 emissions has created significant debate in the past years. The present literature on technological innovation and CO_2 emission concentrates on research and development investment on general innovation, eco-friendly products innovation, and ecological innovation. Several studies have examined the impact of technology on CO_2 emissions. (Khan et al., 2020; Jiang-Bo Geng and Qiang Ji, 2016; Bilgili et al. 2016; Li et al., 2015; Panwar et al. 2011). The study of Jin et al., (2017) analyses technological innovation in the energy sector on CO_2 emissions in China. The findings of their study revealed that technological advancement lessens CO_2 emissions. Furthermore, Li et al., (2017) also investigated the advancement in technology on CO_2 emissions in China, and their outcomes suggested that the technological process lowers CO_2 emissions. In addition, studies such as Nesta et al. (2014), and Kahouli (2018) have considered several other nations and regions when investigating the linkage between CO_2 emissions of technological innovation. For example, Fernandez et al. (2018) investigate the effect of research and development spending on CO_2 emissions in China, the United States, and the European Union. Their analysis has shown that research and development expenditure in the EU and the USA enhance environmental quality. Similarly, Research and development investment improves environmental degradation in China.

Lantz and Feng (2006) also examine the effect of income, technological innovation, and population on Canada’s CO_2 emissions. Their results indicate that advancement in technology and the economic structure helps to decreases CO_2 emissions. Sohag et al., (2015) examine the interconnection between CO_2 emissions, technological improvement, trade openness, energy use, and economic development. Their study revealed that technological improvements stimulate energy conservation and minimize CO_2 emissions. Furthermore, Luan et al. (2019) found that domestic research and development weakens the strength of CO_2 emission, using the panel dataset. Using ASEAN and BRICS economies as examples, Salman et al. (2019) argued that technological innovation could certainly reduce CO_2 emission by enhancing energy efficiency. Khattak et al. (2020) further claimed that technological innovation reduces CO_2 emission via energy consumption. Contrary to several studies, Shahbaz et al. (2020) examined the effect of energy investment trends on CO_2 emissions and found that public and private investment in the energy sector led to an increase in CO2 emissions. Comparably, Liang et al. (2019) reported that the technological innovation is negatively correlated with the CO_2 emissions.

The move towards environmentally friendly, sustainable products has been going on for a while, and consumer demand for such products has influenced corporate policies. Eco-innovation, often referred to as green innovation, emphasizes friendship with the environment when new goods are made. The effect of eco-innovation on CO_2 emission has received significant attention from scholars. Fethi and Rahuma (2019) empirically investigate the role of eco-innovation in reducing CO_2 emissions over the period 2007-2016 for the top 20 refined oil-exporting countries. Their analysis has shown that eco-innovation (i.e., R&D) has a negative and significant long-term impact on CO_2 emissions. Többelmann and Wendler (2020) also examined the relationship between eco-innovation and CO_2 emissions in 27 EU nations from the period 1992-2014 and found that technological innovation led to reduction in CO_2

emissions, while general innovative does not contribute to a reduction in emissions. Similarly, Mensah et al. (2019) reported that eco-patents and trademarks collectively reduce CO_2 emissions in OECD economies. Du and Li (2019) also assess carbon emission output in 71 economies over the period 1992–2012 using a parametric Malmquist index method that considers both statistical noise and individual heterogeneities. It was reported that green technology innovation reduced CO_2 emissions in high-income economies, and it is difficult to find significant evidence that green technology developments have a positive impact on carbon productivity in less developed economies. Chen and Lee (2020) also examines the effect of technological innovation on CO_2 emissions with spatial econometric models in a panel of 96 countries over the period 1996-2018, and the results of their analysis show that technological innovation can significantly reduce CO_2 emissions in high-income and high-technology countries, while research and development investment in other countries even increase CO_2 emissions.

According to Zhu et al. (2020), Japan is known to be one of the world's largest energy consumers and energy importers. Almost 96 percent of its primary energy supply at the national level relies on imports from other countries. The authors further stressed that renewable energies could improve Japan's energy security by diversifying the energy mix and can be seen as both a real challenge and a strategic opportunity in their energy policy goals that minimize energy import dependence and the country's CO_2 emissions. Several scholars have examined the effect of renewable energy consumption on CO_2 emission. For example, Chen and Lei (2018) examine the nexus between renewable energy consumptions and technological innovation using 30 countries from 1980 to 2014 using a panel quantile regression. The results of their study claim that the effects of CO_2 emissions are varied. In the case of high-emission nations, the use of renewable energy reduces CO_2 emissions due to a decreased proportion of renewable energy used. Further, Bilgili et al. (2016) looked at the possible effect of renewable energy use on environmental quality using a panel of dataset of 17 OECD countries from 1977 to 2010 and reported that renewable energy consumption had a detrimental impact on CO_2 emissions. In addition, Bhattacharya, Churchill, and Paramati (2017) empirically analyzed the effect of renewable energy, institutions on economic production, and CO_2 emissions, using yearly data from 85 developed and emerging economies from 1991 to 2012. Their findings suggest that there is considerable variability across sub-samples and the system-GMM results indicate that the rise of renewable energy consumption has a considerable positive and negative effect on economic growth and CO_2 emissions, respectively. The authors concluded that both the implementation of renewable energy and institutions are critical for fostering economic growth and reducing CO_2 emissions. Khoshnevis-Yazdi and Ghorchi-Beygi (2018) also analyze the effect of economic growth, renewable energy, energy use, financial innovations, trade openness, and urbanization growth on CO_2 emissions using the Pooled Mean Group (PMG) and Granger Causality in 25 African countries over the period 1985-2015. The results of their analysis show that increases in renewable energy use and trade openness minimize CO_2 emissions. Saidi and Omri (2020) also analyzed the short-and long-run impacts of renewable and nuclear energy use on CO2 emissions in 15 OECD countries over the period 1990-2018 using both the FMOLS and the VECM techniques. Specifically, their results have shown that investment in renewable energy reduces CO_2 emissions in Japan.

Furthermore, Usman et al. (2020) use quarterly data from 1985 to 2014 to analyze the role of renewable energy and globalization in the United States ecological footprint. Their empirical evidence shows that renewable energy exert negative impact on ecological footprint, while financial growth and globalization exert positive impact on ecological footprint. Alola et al. (2019) examined the impact of role of macroeconomic indicators on environmental degradation in United States between 1960 and 2015. The investigators utilized the ARDL approach to establish this interconnection. The empirical findings show that urban population increases the cooling degree days. Usman et al. (2020) in their study on the link between renewable energy and environmental sustainability established that trade openness and renewable energy mitigate ecological footprint in United States. Using G-7 as a case study, Ike et al. (2020) examined the interconnection between renewable energy and environmental sustainability. The empirical outcomes validate the EKC hypothesis while energy price, and renewable energy improves the quality of the environment. Alola and Kirikkaleli (2019) using Gradual shift and wavelet approaches examined the co-movement and long-term and short-term causal relationship between CO_2 emission renewable consumption, immigration, and healthcare in the United States. The empirical outcomes revealed feedback casualty between CO_2 emissions and renewable energy. Alola et al. (2019) investigated the impact of renewable energy, and migration on environmental sustainability using European Union's largest economies between 1990 and 2016. The outcomes show that renewable energy improves environmental quality while migration harms the quality of the environment.

The association between economic growth and CO_2 emissions has been studied extensively empirically for over two decades, and the connection between CO2 emissions and economic growth has been shown to exist. A study like Hu et al. (2020) explores the spatial-temporal evolution of CO_2 emission decoupling and driving factors in 57 countries from 1991 to 2016. Nearly all countries' CO_2 emissions have been found to increase dramatically due to economic growth, while energy intensity decreases CO_2 emissions to some degree. The study of Odugbesan and Adebayo (2020) in Nigeria also established positive interconnection between CO_2 emissions and economic growth. Muhammad (2019) also examine the effect of economic growth, energy use, and CO_2 emissions in 68 countries using panel data for the period 2001–2017 for MENA countries. Their empirical findings indicate that economic growth increase with an increase in energy consumption in developed and developing countries while declined in MENA countries while CO_2 emissions increase in all countries due to an increase in energy consumption. Furthermore, Rahman, Saidi, and Mbarek (2020) investigate the effect of CO_2 emissions, population size, and trade openness on the economic growth of five South Asian countries using data from 1990 to 2017 by applying the panel co-integration method of the extended neoclassical growth model. The results obtained show that South Asia's economic growth is influenced by CO_2 emissions, population density positively and trade openness negatively.

The study of Adebayo (2020a) on the linkage between economic growth and environmental quality in Mexico revealed positive interconnection between CO_2 emissions and economic growth. Furthermore, Kirikkaleli et al. (2020) examined the determinants of ecological footprint in Turkey using dual gap approach. The empirical outcomes reveal that economic growth harms the quality of the environment. Also in South-Africa the study of Odugbesan and Adebayo (2020) established positive linkage between economic growth and CO_2 emissions. The above studies' empirical findings show a lack of agreement in the literature on technological innovation, the use of renewable energy, and economic growth on CO_2 emission. Country or region heterogeneity concerning levels of innovation, economic development, and energy use patterns are the key reasons for these disagreements. Country or region-specific studies are therefore necessary in order to alleviate the current literature debate. Hence, this study focuses on Japan's unique characteristics and will thus add significantly to the existing literature.

We add to the literature in the following ways; (i) the study utilize Zivot and Andrew (2002) unit root test to evaluate the stationarity property and structural break respectively; (ii) the study used Maki (2012) co-integration, which consider breaks in variables; (iii) we used FMOLS and DOLS to capture the long-run impact of technological innovation, renewable energy, economic growth on consumption-based CO_2 emissions; (iv) Breitung and Candelon (2006) Frequency-Domain Causality was also used to detect the causal relation in the short-run, medium-run and long-run between consumption-based carbon emissions and independent variables; and (v) we addressed the gap in literature by utilizing consumption-based carbon emissions which is adjusted for trade. The third segment discusses the material and methods used. The fourth segment contains outcomes based on implemented approaches. Conclusion and policy direction is discussed in the fifth segment.

MATERIALS AND METHOD

The current study aims at examining the effect of Japan's renewable energy (REN), technology innovation (TI), and economic growth (GDP) on consumption-based carbon emissions (CCO_2) from the period 1992Q1 to 2015Q4. This research utilizes a quadratic match-sum technique to turn annual data into quarterly data due to the unavailability of data and resolve a small sample size. This conversion method has been used in previous studies (Kirikkaleli, 2019; Shahbaz et al. 2020; Khan et al. 2020a; Khan et al. 2020b; Kirikkaleli and Adebayo 2020; Akinsola and Adebayo, 2021), and it is not only significant to minimize adjustments of points but also to change seasonal disparities through the transition from lower bound to higher bound frequency data. The series used is transformed into a log form. This is done to ensure that the data comply with normality (Katırcıoğlu et al. 2016; Onyibor et al. 2018; Beton and Adebayo 2020; Shahbaz et al. 2013). In this study, the regressors are GDP, TI, and REN, while CCO_2 is the dependent variable. CCO_2 represents consumption-based carbon emissions per-capita and defined as emissions from fossil fuels subtracting exports and adding imports with a unit of one million tonnes of carbon emissions (mt CO_2). Economic growth is also calculated as GDP per capita constant 2010 US$. Technological innovation is measured as both resident and non-resident patent applications. Renewable energy usage is measured as share of final energy consumption. In addition, all the data is derived from the World Bank database with the exemption of consumption-based carbon emissions. Equations 1, 2, and 3, revealed the economic function, economic model, an econometric model of the study:

$$CCO_{2t} = f\left(GDP_t, REN_t, TI_t\right) \tag{1}$$

$$CCO_{2t} = \vartheta_0 + \vartheta_1 GDP_t + \vartheta_2 REN_t + \vartheta_3 TI_t \tag{2}$$

$$CCO_{2t} = \vartheta_0 + \vartheta_1 GDP_t + \vartheta_2 REN_t + \vartheta_3 TI_t + \varepsilon_t \tag{3}$$

In Equations 1, 2, and 3, CCO_2, REN, TI, and GDP illustrate consumption-based carbon emissions, renewable energy, technological innovation, and real growth. The purpose of utilizing the GDP, REN, TI, and PPIE in Equation 3 are specified here. Several studies have been performed over the decades on these experiences (Halicioglu, 2009; Sadorsky, 2012; Shahbaz et al. 2013; Jayanthakumaran et al. 2012; Hossain, 2011). None prior studies used Consumption-based carbon emissions as a proxy of environmental degradation. Based on prior studies, economic growth is expected to deteriorate environmental quality (Awosusi et al. 2020; Lee and Yoo, 2016; Kalmaz and Kirikkaleli, 2019; Sarkodie, 2018; Rana and Sharma, 2019), while renewable energy is expected to improve the quality of the environment (Khan et al. 2020c). Furthermore, technological innovation will reduce emissions (Brock and Taylor, 2005; Tang and Tan, 2013; Khan et al. 2020a; Shahbaz et al. 2020; Khan et al.

2020b). The technological innovation is expected to enhance quality of the environment. Apart from technological innovation and economic growth, this study also involves using renewable energy as a predictor of CCO_2. Renewable energy usage is seen as one of the vital drivers of carbon emissions reduction (Pata, 2018; Jebli et al., 2016; Shahbaz et al., 2020; Inglesi-Lotz and Dogan, 2018).

Traditional unit-root tests, including Augmented Dickey-Fuller (ADF), Dickey-Fuller (DF), and Phillips and Perron (PP), cannot be used if a structural break occur in time series data due to non-authentic and prejudiced outcomes that may result in null hypothesis rejection (Shahbaz et al., 2013; Adebayo, 2020b; Katircioglu, 2009; Eminer et al. 2020). This study adopted Zivot-Andrew Root Unit Test suggested by Zivot and Andrews (2002) to capture a single structural break in the series. The Zivot-Andrew test not only tests the root characteristics of each variable but also considers a structural break. The test equation for Zivot and Andrew (2002) is shown as follows:

$$\Delta x_t = \varphi + \varphi x_{t-1} + \pi t + \delta DU_t + \sum_{j=1}^{k} d_j \Delta x_{t-j} + \mu_t \quad (4)$$

$$\Delta x_t = \varphi + \varphi x_{t-1} + \pi t + \gamma DT_t + \sum_{j=1}^{k} d_j \Delta x_{t-j} + \mu_t \quad (5)$$

$$\Delta x_t = \beta + \beta x_{t-1} + \beta t + \theta DU_t + \theta DT_t + \sum_{j=1}^{k} d_j \Delta x_{t-j} + \mu_t \quad (6)$$

There are three choices for implementing the root test of the Zivot-Andrews unit. They are; at the intercept, trend and intercept, and trend. The preceding model can be captured where the dummy variable is depicted by DU_t, which demonstrates a shift that occurred at a breakpoint. DTt illustrates the trend in the shift. The empirical analysis utilizes model 6.

Therefore,

$$DU_t = \begin{cases} 1\ldots..if\ \ t > TB \\ 0\ldots..if\ \ t < TB \end{cases} \text{ and } DU_t = \begin{cases} t - TB \ldots.\ if\ \ t > TB \\ 0\ldots.. \quad\quad if\ \ t < TB \end{cases} \quad (7)$$

Taking into account structural break (s), we utilize the Maki co-integration test to investigate the null hypothesis of a non-co-integrating interconnection between TI, REN, GDP, and CCO_2 emissions in Japan, Unlike the Gregory and Hansen (1996) and Hatemij (2008) co-integration tests, which also contain structural breaks, the Maki co-integration test is adopted since it can capture five unknown structural breaks when analyzing the co-integration interconnection between the series. Maki suggests four regression frameworks (2012), namely; (i) level shift (ii) level shift with the trend; (iii) regime shift and trend; and (iv) regime shift with the trend. The regressions mentioned above are illustrated by Equations 8-11 respectively as follows;

$$Y_t = \rho + \sum_{i=1}^{k} \rho_i D_{i,t} + \theta' Z_t + \varepsilon_t \quad (8)$$

$$Y_t = \rho + \sum_{i=1}^{k} \rho_i D_{i,t} + \theta' Z_t + \sum_{i=1}^{k} \theta' Z_t D_{i,t} + \varepsilon_t \quad (9)$$

$$Y_t = \rho + \sum_{i=1}^{k} \rho_i D_{i,t} + \theta' Z_t + \sigma t + \sum_{i=1}^{k} \theta' Z_t D_{i,t} + \varepsilon_t \quad (10)$$

$$Y_t = \rho + \sum_{i=1}^{k} \rho_i D_{i,t} + \theta' Z_t + \sigma t + \sum_{i=1}^{k} \sigma' D_{i,t} + \sum_{i=1}^{k} \theta' Z_t D_{i,t} + \varepsilon_t \quad (11)$$

In Equations 8-11, t denotes time, that is, t = 1, 2… T. The dependent variable is CO_2, which is represented by Y_t. Z_t represents the independent variables, while ε_t stands for the error term.

Pesaran et al. (2001) bounds test is used to detect the long-term co-integration of variables due to three key advantages over conventional co-integration frameworks. Firstly, when variables are integrated in mixed order; secondly, it is somewhat more robust for small sample sizes (Narayan and Narayan, 2004); and thirdly, for impartial long-term association (Harris and Sollis 2003). If the computed F-statistic is higher than the upper and lower bond critical value, the null hypothesis of no co-integration hypothesis is rejected. This analysis, therefore, used the ARDL bounds test to evaluate the long-run co-integration between the variables. The ARDL bounds test approach for this study is specified in Equation 12 as follows;

$$\Delta CCO_{2t} = \vartheta_0 + \beta_1 CCO_{2t-1} + \beta_2 GDP_{t-1} + \beta_3 REN_{t-1} + \beta_4 REN_{t-1} + \sum_{i=1}^{t}\vartheta_1 \Delta CCO_{2t-i} + \sum_{i=1}^{t}\vartheta_2 \Delta GDP_{t-i} + \sum_{i=1}^{t}\vartheta_3 REN_{t-i} + \sum_{i=1}^{t}\vartheta_4 \Delta TI_{t-i} + \varepsilon_t \tag{12}$$

The corresponding long-run multipliers are shown by parameters ϑ (i = 1, 2, 3, and 4), while the short-run dynamic coefficients are represented by parameters β_1 (i = 1, 2, 3, and 4) of the basic ARDL model.

A single co-integrating vector will be measured for evaluating the long-term interconnection. There are several econometric methods in this regard, which can explore the long-run relationship between the estimated variables. The Fully Modified OLS (FMOLS) introduced by Phillips and Hansen (1990) and Dynamic OLS methods introduced by Stock and Watson (1993) are used in this research. These methods allow asymptotic coherence to be achieved by considering the effect of serial correlation and the test of endogeneity that results from the presence of a co-integrating relationship. Only if the criterion of co-integration among the variables is met can FMOLS, DOLS, and CCR be enforced. Therefore, long-term elasticity is measured in this analysis using FMOLS and DOLS estimators.

The current research also aims to outline the causal impact of TI, GDP, and REN on consumption-based carbon emissions (CCO_2) at various frequencies in Japan. Therefore, this research uses the Breitung and Candelon (2006) frequency-domain causality test. The key difference between the time domain and the frequency domain technique is that the time domain method tells us where a particular shift occurs within a time series, while the frequency domain measures the magnitude of a particular variance in the time series (Gokmenoglu et al. 2019; Khan et al. 2020a). According to Breitung and Candelon (2006), the frequency-domain permits eliminating seasonal fluctuations in small sample data. In addition, the authors stressed that non-linearity and causality phases might be detected by the frequency domain test, while the test also enables the identification of causality between low, medium, and long frequency variables. Finally, the frequency-domain causality test allows us to differentiate long-term causality from short-term causality within time-series (Breitung and Candelon, 2006). The test is shown as follows;

Xt = [Ht, Ct, Dt], where Xt is the three-dimensional vector of the endogenous and stationary variables noticed at time t = 1, …, T. Xt is assumed to have a finite-order VAR illustration procedure as;

$$\Theta(L) X_t = \epsilon_t \tag{13}$$

Where ΘLwhich denotes 3x3 polynomial lag order of p is ( )illustrated as $\Theta(L) = I - \Theta_1 L^1 \ldots - \Theta_p L^p$ with $L^K X_t = X_{t-k}$. ϵ_t illustrates the error term, which follows the process of white noise with zeros expectancy and $(\epsilon_t\ \epsilon_t^{\iota}) = \Sigma$. Σ denotes the positive and symmetric. For simplicity of analysis, in line with Breitung and Candelon's (2006) analysis, no deterministic terms are applied to the Eq. (12). $G^{\iota}G = \Sigma^{-1}$ is Cholesky decomposition, while G stands for the lower triangle-matrix. Also, G^{ι} stands for the upper triangle-matrix. $E(n_t n_t^{\iota}) = I$ and $n_t = G\epsilon_t$. Utilizing the decomposition of Cholesky, the MA description of the framework is defined as:

$$X_t = \begin{bmatrix} H_t \\ C_t \\ D_t \end{bmatrix} = \Theta(L)\varepsilon_t = \begin{bmatrix} \Theta_{11}(L) & \Theta_{12}(L) \\ \Theta_{21}(L) & \Theta_{22}(L) \\ \Theta_{31}(L) & \Theta_{32}(L) \end{bmatrix} \begin{bmatrix} \varepsilon_t \\ \varepsilon_t \\ \varepsilon_t \end{bmatrix} \quad (14)$$

$$X_t = \begin{bmatrix} H_t \\ C_t \\ D_t \end{bmatrix} = \Phi(L)\Pi_t = \begin{bmatrix} \Phi_{11}(L) & \Phi_{12}(L) \\ \Phi_{21}(L) & \Phi_{22}(L) \\ \Phi_{31}(L) & \Phi_{32}(L) \end{bmatrix} \begin{bmatrix} \Pi_t \\ \Pi_t \\ \Pi_t \end{bmatrix} \quad (15)$$

Where Θ(L) = Θ(L)$^{-1}$ and Φ(L) = ΦL)G^{-1}. By utilizing this depiction, the spectral density of H_t can be illustrated as follows:

$$f_H(\psi) = \frac{1}{2\pi}\left\{|\Phi_{11}\left(e^{-i\varphi}\right)|^2 + |\Phi_{12}\left(e^{-i\varphi}\right)|^2\right\} \quad (16)$$

In Eq. 15 and 16, Ht can be defined as the addition of two insignificant MA procedures: an integral part guided by previous Ht implementation and an element containing the predictive ability of the Ct Dt variables. The Ct and Dt variables predictive power can be calculated regarding the spectrum's predictive portion at each frequency of the Ct and Dt variables. The Granger causality null hypothesis is checked in the series. For example, Ct does not Granger cause H_t at the frequency ψ if the Ht spectrum's predictive factor at the frequency ψ is 0. This is the explanation for the estimate of causality proposed by Hosoya (1991) and Geweke (1982) and described as follows;

$$M_{x\to y}(\psi) = In\left[\frac{2\pi f_y(\psi)}{|\Phi_{11}(e^{-i\varphi})|^2}\right] \quad (17)$$

$$In\left[+\frac{|\Phi_{12}(e^{-i\varphi})|^2}{|\Phi_{11}(e^{-i\varphi})|^2}\right] \quad (18)$$

The above equations linked to Geweke's estimation would be zero (0) when $|\Phi_{11}(e^{-i\varphi})|^2 = 0$. A simple linear constraint is extended to the VAR equation (1), as described as follows;

$$CCO_{2t} = \theta_1 GDP_{t-1} + \theta_\delta GDP_{t-\delta} + \gamma_2 REN_{t-1} + \gamma_\delta REN_{t-\delta} + \gamma_3 TI_{t-1} + \gamma_\delta TI_{t-\delta} + \varepsilon_t \quad (19)$$

Where the coefficients of the lag polynomials are illustrated by $\theta's\ and\ \gamma's$. The null hypothesis $M_{x\to y}(\psi) = 0$ equal to the linear constraint,

$$H_O : R(\psi)\gamma = O \quad (20)$$

Where $\gamma = [\gamma_1, \ldots\ldots \gamma_\delta]^{\iota}$ is the vector coefficient, whereas R(ψ) is explained below:

$$R(\psi) = \left[\frac{\cos(\psi)\cos(2\psi)\ldots\cos(\delta\psi)}{\sin(\psi)\sin(2\psi)\ldots\sin(\delta\psi)}\right] \quad (21)$$

The standard F-stat is estimated as F (2, T− 2p) for $\psi\ \varepsilon(0, \pi)$, where 2 is the number of limitations, and T is the number of the observations utilize to calculate the VAR framework of order p.

RESULTS AND DISCUSSION

The descriptive study statistic is depicted in Table 1. Economic growth (GDP) ranges from 4.40 to 4.46, technological innovation (TI) ranges from 5.50 to 5.64, consumption based CO2 emissions (CCO_2) ranges from 3.06 to 3.12, and renewable energy (REN) ranges from 4.58 to 4.67. All the variable's natural logarithm was taken with the exemption of REN. The skewness reveals that all the variables are normally distributed. Additionally, the kurtosis shows that all the variables are normally distributed with the exemption of GDP. Furthermore, the Jarque-Bera probability reveals that only GDP conform to normality.

Table 1. Data Description

Variable	Consumption-based CO_2 Emission	Economic Growth	Technology Innovation	Renewable Energy
Code	**CCO_2**	**GDP**	**TI**	**REN**
Source	IMF	World Bank	World Bank	World Bank
Time-Frame		1990Q1-2015Q4		
Mean	3.0945	4.5684	5.5769	4.6303
Median	3.0976	4.5705	5.5733	4.6272
Maximum	3.1202	4.6947	5.6436	4.6730
Minimum	3.0639	4.4041	5.5034	4.5806
Std. Dev.	0.0155	0.0589	0.0403	0.0246
Skewness	-0.4646	-0.0845	-0.0738	-0.1342
Kurtosis	2.1382	3.2889	1.6772	1.9263
Jarque-Bera	6.7599	0.4717	7.4546	5.1542
Probability	0.0340	0.7898	0.0240	0.0759
		Correlation Matrix		
CCO_2	1			
GDP	0.4001	1		
TI	0.2685	-0.3642	1	
REN	0.6671	0.4946	-0.1221	1

It is essential to explore the order of integration amongst the series before examining the linkage between CCO_2, GDP, TI, and REN in Japan. Thus, the study utilizes the Zivot-Andrews (ZA) unit root test to investigate the order of integration. The study used the ZA because if there is evidence of the structural break in series, the conventional unit root tests such as ADF, PP, and KPSS will yield misleading results. Table 2 reveals the series order of integration. The findings revealed that CCO_2 and REN are stationary at level, i.e., I(0). However, after taking the first difference, i.e., CCO_2, GDP, and TI, are stationary. These findings demonstrate that the variables are stationary at a mixed level I(0) and I(1).

Table 2. Zivot–Andrews unit-root test

Variables		Level		First Difference		Decision
		T-statistic	**Break-Year**	**T-statistic**	**Break-Year**	
CCO_2	K andT	-5.6266**	2007Q2	-5.0363**	2009Q2	I(0) I(1)
GDP		-4.3403	2008Q4	-4.8771***	2008Q2	I(1)
REN		-6.3788*	2008Q2	-4.3486	2007Q2	I(0)
TI		-3.5433	1999Q2	-6.010*	2001Q2	I(1)

Note: $^{B\text{ and }C}$ stands for 1%, 5% significance level respectively

Since there is evidence of the structural break in the series, the current study employed Maki (2012) co-integration test to investigate the long-run co-integration amongst the variables. This test takes into consideration five breaks. Table 3 illustrates the findings from the Maki co-integration test. The findings reveal evidence of co-integration amongst the series. Thus, we reject the null hypothesis of no co-integration between CCO_2, GDP, TI, and REN.

Table 3. Maki co-integration test

Model	T-stats	CV-5%	Break-Year(s)
		Trend and Regime shifts	
CCO_2=*f*(GDP, REN, TI)	-20.089*	-6.911	2013Q4
	-20.089*	-7.638	2013Q4, 2001Q2
	-20.089*	-8.254	2013Q4, 2001Q2, 2009Q4
	-20.089*	-8.871	2013Q4, 2001Q2, 2009Q4, 1998Q1
	-20.089*	-9.482	2013Q4, 2001Q2, 2009Q4, 1998Q1, 1993Q3

Note: CV illustrates the critical value and 1% significance level is signified by *

Furthermore, as a robustness check to the Maki co-integration, the study utilized the ARDL bounds test. This test is employed when the series are I(0) and/or I(1) but not I(2). The findings from the ARDL bounds test are depicted in Table 4. Since the F-stat(9.959) is greater than the lower and upper bound critical values, the null hypothesis of no co-integration is rejected. This result complies with the outcome of the Maki co-integration tests.

Table 4. Bounds Test

Model	CCO_2=f(REN, TI, GDP)		
F-statistic	9.959*		
Co-integration	Yes		
	Significance Level	LB	UB
	10%	2.72	3.77
	5%	3.23	4.35
	2.5%	3.69	4.89
	1%	4.29	5.61

Note: * illustrates 1%, significance level, LB and UB denotes lower band and upper bound critical value

Since there is evidence of co-integration amongst the series, the present paper utilized the FMOLS and DOLS to explore the long-run and short-run linkage between CCO_2 and REN, GDP, and TI. The result of the FMOLS and DOLS are presented in Table 5. The findings from the FMOLS and DOLS long-run estimators revealed; (i) Positive linkage between GDP and CCO_2. Therefore, holding other indicators constant, a 1% increase in GDP will trigger CCO_2 by 0.018% and 0.028% as revealed FMOLS and DOLS. This implies that economic growth In Japan harms environmental quality. This is also evident as Japan contributes 3% of the total CCO_2 emission globally. This outcome is similar to the findings of Khan et al. (2020a), Shabahz et al. (2020), and Khan et al. (2020c) (ii). As expected, TI innovation exerts a negative impact on CCO_2 emissions in Japan. This illustrates that 0.277% and 0.23% decrease in CCO_2 emissions is due to a 1% increase in TI as revealed by FMOLS and DOLS, respectively. This reveals that technological innovation improves the quality of the environment in Japan. This result complies with previous studies (Khan et al. 2020a; Shabahz et al. 2020; Khan et al. 2020b) who found a negative linkage between TI and CCO_2. Thus, technology innovation can enhance the quality of the environment without imposing a tax on the polluters. (iii) There is a negative and significant link between REN and CCO_2. This implies that renewable energy enhances environmental quality in Japan. This is because renewable technology utilizes clean energy sources that are safe and please current and probable necessities; it is also a source of CCO_2 emissions reduction. This outcome concurs with the results of Khan et al. (2020a), Khan et al. (2020b), and Shahbaz et al. (2020).

Additionally, the R^2 disclose that that TI, REN, and GDP can explain 97% of discrepancy in CCO_2 emissions correspondingly, whereas the remaining 3% is attributed to the error term.

Table 5. Long-run estimators

Variables	FMOLS	DOLS
	-1.019	-1.033
REN	(-8.725)	(-5.963)
	[0.000]*	[0.000]*
	-0.277	-0.230
TI	(-3.315)	(-2.453)
	[0.001]*	[0.015]**
	0.018	0.028
GDP	(3.241)	(3.397)
	[0.001]*	[0.001]*
	0.107	0.133
C	(3.585)	(2.655)
	[0.000]**	[0.000]**
R-squared	0.97	0.97
Adj R^2	0.97	0.97
SE of Regression	0.002	0.002

Note: * and ** indicate significance level at 10%, 5% and 1%. () includes t-statistics, [] includes p-values. C and T donates constant and trend, respectively.

After establishing the long-run interconnection between CCO_2, REN, GDP, and TI, we utilized Candelon and Breitung (BC) frequency-domain causality test to capture the causal linkage between CCO_2, REN, GDP, and TI in Japan at various frequencies. The results of the BC causality test are depicted in Table 6. The findings reveal that; (a) REN causes CCO_2 in the short-term, medium-term, and long-term. This demonstrates that REN can predict significant variations in CCO2. The result corresponds to Khan et al. (2020a) and Shahbaz et al. (2020b). (ii) In the medium-term and long-term, TI Granger causes CCO_2. This illustrates that TI can predict CCO_2. Therefore the null hypothesis of no causality is rejected. (iii) In the long-term, GDP Granger causes CCO_2 in Japan. This illustrates that GDP can predict CCO_2. This outcomes is as same as the results of Shahbaz et al. (2020).

Table 6. Breitung and Candelon (2006) Frequency-Domain Causality Test

	Long-term		**Medium-term**		**Short-term**	
Causality Path	w_i=0.01	w_i=0.05	w_i=1.00	w_i=1.50	w_i=2.00	w_i=2.50
REN→CCO_2	8.8121**	8.8131*	7.5346**	7.5301**	6.7346**	6.9705**
TI →CCO_2	16.372*	16.370*	6.5224**	6.745**	2.3710	2.3710
GDP →CCO_2	9.4311*	9.4312*	2.3654	2.3661	2.1620	2.1320

Note: <> and () stands for Wald test statistic and p-value, respectively. The path of causality is represented by→. 10%, %5, and 1% significance levels are illustrated by *, ** and ***, correspondingly. SIC is used to verify the VAR models lag lengths.

CONCLUSION

This paper investigates the long-run and causal impact of technological innovation (TI), economic growth (GDP), and renewable energy (REN) on consumption-based CO_2 carbon emissions (CCO_2) in Japan. The study utilized quarterly data spanning between 1990 and 2015. The study utilized recent econometrics techniques such as Maki co-integration, ARDL bunds test, FMOLS, DOLS, and frequency domain causality techniques. We addressed the gap in literature by utilizing consumption-based carbon emissions which is adjusted for trade. Thus, this empirical analysis contributes to the literature. The findings from the ARDL bounds and Maki co-integration tests revealed evidence of co-integration amongst the series. The FMOLS and DOLS reveal that both TI and REN improve the quality of the environment, while GDP harms the environment's quality. The frequency-domain causality technique findings reveal that TI, REN, and GDP can significantly predict CCO_2 in Japan. Based on these outcomes, the government of Japan should be careful when formulating policies that trigger growth, which will have a detrimental impact on the environment's quality. Based on these outcomes, we suggested that Japan's government should be careful when formulating policies that trigger growth, which will have a detrimental impact on the environmental quality. Additionally, any policy that encourages renewable energy should be encouraged since it enhances environmental quality. Furthermore, this paper encourages environmental innovation since it curtails consumption-based carbon emissions. Although the present paper explores significant results for Japan's case, the major setback in this analysis is the availability of data. Japan can also introduce carbon capture and storage technologies with the potential to minimize the CO_2 emitted by the use of fossil fuels in power generation and airborne manufacturing processes. In addition, for the short-term control of CO_2 emissions, the introduction of the carbon tax should be considered by decision-makers to enact polluters to avoid environmental waste at the minimum. In addition, future studies should be conducted by utilizing other determinants of environmental degradation and several countries as a case study.

GRANT SUPPORT DETAILS

The present research did not receive any financial support.

CONFLICT OF INTEREST

The authors declare that there is not any conflict of interests regarding the publication of this manuscript. In addition, the ethical issues, including plagiarism, informed consent, misconduct, data fabrication and/ or falsification, double publication and/or submission, and redundancy has been completely observed by the authors.

LIFE SCIENCE REPORTING

No life science threat was practiced in this research.

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