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Environmental Management Technologies, Environmental Policy Stringency, Energy Productivity and Pollution Emission: Fresh Evidence from Indonesia under STIRPAT Framework

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ABSTRACT

The rapid pace of climate change and global warming has become an ever growing challenge all over the world. Global warming and carbon concentrations can be mitigated by adopting strict environmental policies and effective management of the environment. Therefore, the study aims to empirically investigate the effect of environmental policy stringency (EPS), energy productivity and environmental management technologies (EMT) on pollution emission in Indonesia-one of the most polluting countries of the world. To this end, the study collects data over the 1990-2020 period. The study uses Autoregressive Distributed Lag Model (ARDL) approach to carry out empirical estimation. The findings reveal that environmental management technologies, energy productivity and environmental policy stringency had negative impact on CO_2 emission. However, economic growth (GDP) and urbanization had positive role in increasing CO_2 emission in the long run and the short run. On the basis of the outcomes, the study recommends that Indonesia should adopt strict environmental policies and legislations to mitigate environmental deterioration. Indonesian government is recommended to promote the adoption of environmental management technologies by providing substantial incentives and investment opportunities for businesses.

Keywords: Environmental Management Technologies, Environmental Policy Stringency, Energy Productivity, CO_2 Emission, Indonesia
JEL Classifications: O31; O39; Q54

1. INTRODUCTION

The excessive CO_2 emission from industries, power plants and many other sources are playing significant role in raising the temperature of earth and global climate change (Al-Maamary et al., 2017). The global temperature has increase upto 0.8 °C with an increase in CO_2 concentration to 400 ppm from 280 ppm (Pachauri et al., 2014). Recently, there is an increase of 408.8 ppm in CO_2 concentration (Kumar et al., 2018) and it is predicted to increase further upto 600-700 ppm by the end of the century causing average temperature to increase upto 4.5-5 °C (Leung et al., 2014). There are several uncertain sociological, technological and economic changes along with natural and human developments that are the leading causes of global warming and high CO_2 concentrations. According to Intergovernmental Panel on Climate Change (IPCC), there is a need to reduce GHG emissions upto 50-80% by 2050 to prevent the danger of planet collapse by catastrophic reasons. In this regard, the policies or strategies recommended by COP21 include adopting energy efficiency and concentration, employing low carbon and renewable fuels, adopting geo engineering technologies like afforestation, and most significantly adopting environmental management techniques (EMT) and environmental policies (Anwar et al., 2018). Empirically, EMT and regulating CO_2 emissions through environmental policies are well recognized as the significant tools in curbing the CO_2 emissions (Hashmi and Alam, 2019). Among environmental regulations and policies, EPS and taxes signify the instruments that authorities commonly use to struggle against the climate change and that turn out to be efficient policies in protecting environmental collapse (Albulescu et al., 2022; Baloch et al., 2021).

Empirically, EPSs have gained prominent interest by recent empirical works (Albulescu et al., 2022; Chien et al., 2021; Wang et al., 2022; Yirong, 2022). Governments of many countries are witnessed to imply strict environmental regulations and concrete actions for climate change mitigation for developing infrastructure for economic green progress to shield climate degradation and resource dearth in energy consumption and efficiency and many other contexts (Dogan et al., 2022; Hanif et al., 2022). Consequently, the environmental regulations and taxation implementations on fossil fuels or transportation, and strategies to promote clean energy production and use are commonly implemented by several countries (Chien et al., 2021; Yirong, 2022). To highlight the stringent environmental regulations benefits, Galeotti et al., (2020) found that governments should implement precise environmental policies to drop the community contagion during the price wedge curtailing between green and non-green innovations (Afshan et al., 2022). Moreover, by introducing way for green growth through increased eco-efficient technology and recycling while lessening risky emanations as well as resource depletion, strict environment-policies are expected to evaluate the effectiveness of various environmental regulations (Afshan et al., 2022; Haq et al., 2020).

Moreover, technology needs for economic activities, assessments; capacity building and technology information has occupied the Centre of attention of climate debaters. Need to adapt to new technology is emphasized in the most recent SDG report-2020 in order to accomplish the SDGs by 2030. Focusing on encouraging innovation in environmental management technology, according to environmentalists, can help heal the damage caused by climate change and, consequently, may stop the trend of global warming and climate change (Hussain et al., 2021; Rej et al., 2023). Countries are eagerly investing and collaborating in environmental management technologies for better environmental awareness. The countries, in collaboration with each other are continuously enhancing the adoption of environmental management technologies and abatement of climate change (Khan et al., 2023; Zhang et al., 2023). Understanding the significance of environmental technologies to mitigate climate change is not a new field of research (Liu et al., 2023). Some of the studies elaborated the positive effect of environmental management technologies on environmental quality in developed or industrialized countries. However in developing or emerging countries, contradictory findings have been found which necessitates the re-examination of the role of environmental management technologies in improving environmental sustainability. Like Santra (2017) found that environmental management technologies do not have positive signs for environmental quality. Sinha et al., (2020) found that environmental management policies were unsuccessful in mitigating environmental pollutions. Therefore, there is a need to further investigate the environmental technologies and environmental degradation nexus.

In addition to adopting environmental technologies and implementation of strict policies, improving the energy efficiency in production and supply processes is the need of the hour for mitigating environmental pollution because of the most significant role played by energy in all production processes (Mohsin et al., 2021; Salvia et al., 2021). Energy productivity, (according to some recent research studies about energy efficiency), measures the economic advantages received from every unit of power or energy being consumed (Alola and Joshua, 2020; Nawab et al., 2021). In other words, energy productivity refers to an indicator of the economic benefits that a country gains from per unit energy used. Energy productivity is calculated as the ratio between economic growth and economic output and total energy used (for example, barrels of oil and kilowatt hours of power/electricity). The significance of energy productivity in improving environmental quality cannot be denied as it has the ability to reduce cost of energy and enhancing energy efficiency (Huaman and Jun, 2014; Nawaz et al., 2020). Any economy can expand its production base and achieve high economic output by consuming lesser amount of energy by increasing its energy productivity. More specifically, energy productivity has the ability to control CO_2 emissions in three ways. First, its increase leads to a reduction in per unit energy used in manufacturing processes. Second, reduction in energy costs can be realized by increasing energy productivity. Third, by reducing oil imports, carbon emissions can be decreased by energy productivity. Therefore, to attain sustainable development, policy makers and researchers have realized and prioritized the adoption of energy productivity (Choi et al., 2017; Nawaz et al., 2020). Countries become enable in determining the effectiveness of the consumption of energy by energy productivity. Furthermore, increasing the energy productivity from a unit of energy has become a political tool for the governments that can be effectively utilized to achieve the objectives of productivity, maximization of growth and competitiveness (Oyebanji and Kirikkaleli, 2022). Thus, an empirical assessment of the role of energy productivity in CO_2 emissions is imperative (Ding et al., 2021).

Keeping in view the above arguments regarding the efficacy of environmental policies, energy productivity and environmental management technologies in preventing climate changes and CO_2 concentrations, the basic goal of the study is to analyze the impact of these factors on environmental pollution in Indonesia. Indonesia is an interesting case study as it is one of the top polluting countries in the world and occupies the sixth position among the top ten highest green house gas emitter countries (Shah et al., 2021; Sohail et al., 2022). By the end of year 2019 before the COVID-19 outbreak, Indonesia was among the world's rapidly growing emerging markets. In fact, because of high foreign direct investment, the economy enjoyed comparatively stable growth rate of approximately 5.1% in 2019. But, the growth in Indonesia is accompanied by rising CO_2 emissions (as evident in Figure 1) that raise serious environmental concerns (Chien et al., 2023; Shair et al., 2021).

The Indonesian government agreed to reduce emissions of greenhouse gases by setting goals and implementing specific actions when it joined an agreement in 2010 (Aubrée et al., 2016; Baloch et al., 2016). Indonesia has signed nationally determined contribution

(NDC) contract to the UN Framework Convention on Climate Change, and aimed to reduce its pollution by 26% by the year 2030. Capacity building, environmental policies and technology innovations are off course necessary for pollution reduction. Over the years, Indonesian economy is implementing environmental policies and adopting environmental management technologies as their progress is evident in Figure 2 over the period 1995-2019. As the country is on its way to meeting NDC targets, it requires significant progress in its environmental management and environmental policies.

There are two worthy contributions of the present study in the environmental pollution and environmental management literature: First, previously insufficient research has been done to fully understand the function of energy productivity, and only a few studies have been conducted to look at how it relates to carbon emissions. The present research is the pioneering one that analyzes the role of EPS and energy productivity in mitigating environmental pollution in Indonesia. Second and most important, the present study estimated the effect of EMT on CO_2 emissions in Indonesia, while previous studies have extensively analyzed the role of green or ecological technology innovations on pollution emissions (Fethi and Rahuma, 2020; Hafeez et al., 2022; Hanif et al., 2022; Hordofa et al., 2023; Yuan et al., 2022). The study findings will provide deep insights for the Indonesian government and policy makers regarding environmental degradation, environmental management and environmental policies nexuses.

Figure 1: CO_2 emission in Indonesia over 1990-2019 period

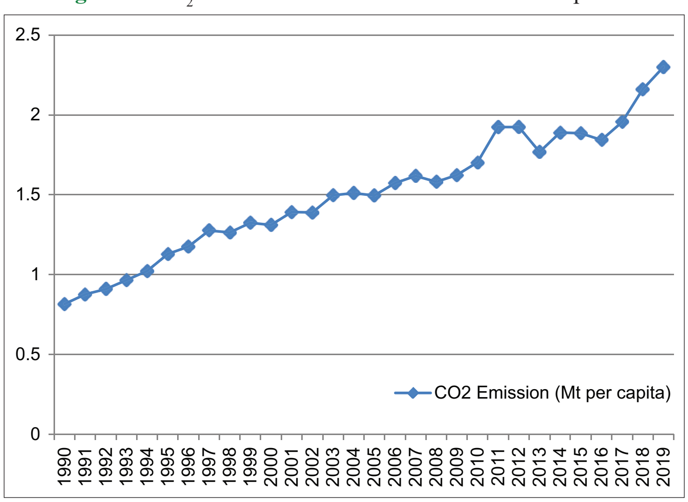
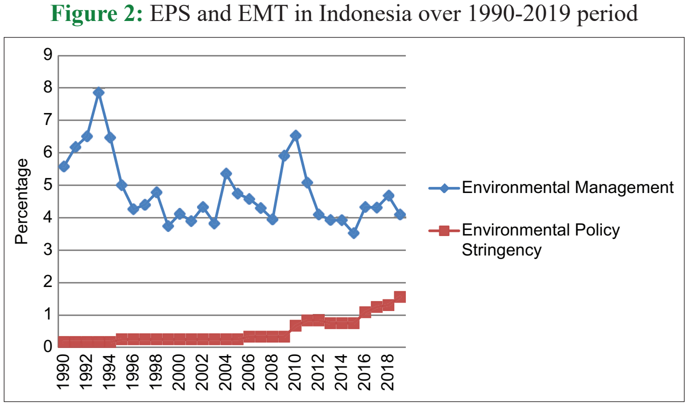


Figure 2: EPS and EMT in Indonesia over 1990-2019 period



The remaining study is organized as follows: Next in Section 2, the review of literature is provided. Section 3 involves data and empirical methodology. In section 4, empirical results and their interpretations are given. And last, in section 5, we provide conclusion and policy implications.

2. LITERATURE REVIEW

2.1. Environmental Policy and Pollution Emission

After (Pigou, 1920) seminal work which highlighted the negative externalities of environmental degradation that cannot be left on the market forces only for suitable solutions, rules and regulations are among the most significant policy instrument to address environmental degradation. Empirical evidences regarding the environmental policies efficacy in mitigating pollution emission is mixed as some studies support that environmental policies have significant impact on emissions, whereas others do not support the argument that environmental policies help in improving environmental quality (Wolde-Rufael and Mulat-Weldemeskel, 2021). Wolde-Rufael and Weldemeskel (2020) estimated the effect of EPS on CO_2 emission in BRIICTS countries (Russia, Brazil, Indonesia, India, Turkey, South Africa and China) over 1993-2014 period. The authors applied PMG-ARDL estimation approach, it was found that initially, EPS did not mitigate the carbon emission, but after reaching a threshold, it had mitigating effect on CO_2 emissions. Wolde-Rufael and Mulat-Weldemeskel (2021) estimated the impact of EPS and environmental taxes on CO_2 emission in Emerging Seven (E-7) economies over 1994-2015 period. Augmented Mean Group estimation approach was used in the study that revealed that environmental taxes and policy had negative impact on CO_2 emission but it took some time to be effective. Albulescu et al. (2022) analyzed the data for 32 countries over 1990-2015 period to analyze the asymmetric effect of EPS on CO_2 emission. Quantile panel fixed effect model was applied that indicated the negative impact of EPS on carbon emission. Likewise, Afshan et al. (2022) analyzed the impact of EPS on ecological footprints in OECD countries over 1990 to 2017 period. Applying MMQR estimation, it was found that environmental policy impact ecological footprints negatively.

In continuation, Sezgin et al. (2021) also investigated the impact of EPS on CO_2 in G-7 and BRICS countries over 1995-2015 period. The findings of panel causality analysis indicated that environmental policy stringency had bidirectional causal association with CO_2 emission. Afshan et al. (2023) considered China as the case study over 2000-2017 period to investigate the effect of EPS on ecological footprints. Applying QARDL estimation, the authors found that EPS had positive effect on ecological footprints in China. Wang et al. (2020) analyzed the effect of EPS on air quality measured by SO_x, NO_x, CO_2, and PM2.5 emissions in OECD countries over 1995-2015 period. System GMM estimation was applied in the study that indicated the negative effect of EPS on SO_x, NO_x and CO_2, however its impact on PM2.5 was weak. Chen et al. (2022) also estimated the role of EPS and air pollution tax on CO_2 emission in China over 1993-2019 period. ARDL and NARDL estimation techniques were used in the study. The findings of ARDL revealed negative impact of EPS and air pollution taxes on CO2 emission. According to NARDL findings, positive shocks in taxes and environmental policies reduced pollution emission whereas negative shocks in both exacerbated pollution emission.

2.2. Environmental Management and Pollution Emissions

The process of technical innovation, which we are concerned with and is acknowledged as an effective method of reducing climate change, is a highly fascinating topic in environmental quality management. Previously, Zhang et al. (2023) studied how climate change mitigation technologies affected carbon emission in 30 OECD countries over 1990 to 2020 period. Applying CD-ARDL, AMG and CCEMG estimations, the authors found that climate change mitigation technologies had positive contribution in CO_2 emission mitigation. Chien et al. (2023) analyzed the effect of EMTs (renewable energy consumption and production) on GHG emissions over 1990-2021 period. Applying NARDL, the outcomes revealed that renewable energy consumption and renewable energy production had negative impact on GHG emissions in China. Xin et al. (2022) explored the nexus between EMT related to chemical sector and CO_2 emission in the USA over the quarterly period from 1990 -2018. The authors found in FMOLS analysis that innovations in environmental technologies and collaboration in environmental technology development had positive contribution in reducing CO_2 emission. Likewise for China, Lin and Zhu (2019) considered the provincial level data of China to estimate the effect of renewable energy technology innovations on CO_2 emission. The findings of panel Threshold regression revealed that renewable technology innovations had negative impact on CO_2 emission. Kamoun et al. (2019) also estimated the renewable energy technologies' role in sustainable development in OECD nations over 1990-2013 period. The study implied that renewable energy technologies had positive effect on sustainable development in OECD countries.

2.3. Energy Productivity and Pollution Emissions

Recently introduced new phenomenon named "Energy productivity" refers to all economic benefits derived from consuming total energy resources. We measure it as \$/MJ and it refers to total primary energy use of an economy (Kirikkaleli et al., 2023). However this phenomenon is relatively less explored in the existing literature in terms of its role in determining environmental quality. Like Abbasi et al. (2023) estimated the effect of energy productivity on consumption based CO_2 emission in Iceland over the period from 1995 to 2019. Fourier ARDL model was in the study that revealed that energy productivity had negative effect on consumption based carbon emission in Iceland. Kirikkaleli et al. (2023) estimated the impact of energy productivity on environmental pollution in Ireland over quarterly period 1990-2019. Applying NARDL approach, it was concluded that energy productivity had negative effect on pollution emission in Ireland. Likewise, Ding et al. (2021) estimated the role of energy productivity in consumption-based CO_2 emission in G-7 economies over 1990 to 2018 period. The findings of second generation panel data estimation indicated that energy productivity had positive contribution in mitigating CO_2 emission. Likewise, Addai et al. (2023) also estimated the energy productivity's impact on carbon emission in Netherland using quarterly data over 1990 to 2019 period. The authors used Fourier ARDL estimation technique and found that energy productivity had negative impact on CO_2 emission in Netherlands.

2.4. Literature Gap

The review of existing literature reveals some gaps that need to be filled. First, the role of renewable energy technologies in environmental degradation was studied by most research studies and only limited studies are found that investigated the effect of environmental management technologies on CO_2 emission and conclusions is still not clear. Similarly, only a limited number of studies have tried to explore the role of environmental policy stringency and energy productivity in CO_2 emission mitigation in the context of different countries and Indonesia, to the best of the author's knowledge, never got attention for the exploration of these roles. Therefore, the study intends to fill in these gaps by estimating the role of environmental policy, energy productivity and environmental management on CO_2 emission in Indonesia and therefore is a significant contribution in environmental pollution literature in general and indonesia's literature in particular.

3. DATA AND METHODOLOGY

To specify the model, the STIRPAT model is followed by the study that was developed by Dietz and Rosa (1994) and York et al. (2004). The existing literature extensively followed this model to estimate the impacts of various socioeconomic variations on environmental quality. The STIRPAT model in its general form is expressed as follows:

$$I_i = \alpha P_i^{\beta} A_i^{\gamma} T_i^{\delta} \varepsilon_i \tag{1}$$

In above equation, environmental quality is denoted by I, population is denoted by P, T represent technology and A denotes affluence. α, β, δ and ɣ are intercept and exponents whereas ε is the disturbance term.

The logarithmic formulation of the above equation is represented as:

$$logI_i = \alpha + \gamma logA_i + \beta logP_i + \delta logT_i + \varepsilon_i \tag{2}$$

Replacing I with CO_2 emission, P with urban population, T with environmental management technologies and affluence with economic growth and with previous literature support, the model is specified in equation (3) as:

$$CO_{2t} = \beta_0 + +\beta_1 EPS_t + \beta_2 EMT_i + \\ \beta_3 GDP_t + \beta_4 ENP_t + \beta_6 URB_t + \varepsilon_t \tag{3}$$

Where EPS denotes environmental policy stringency, EMT shows environmental management technologies, GDP shows economic growth, ENP stands for energy productivity and URB shows urbanization.

The detailed variable descriptions and their data sources are shown in the following Table 1.

3.1. Empirical Methodology

The analysis uses the method proposed by Pesaran et al. (2001) known as the ARDL which is an effective estimating tool to identify short-run and long-run relationships among variables of a given model due to its many advantages over the standard cointegration methods. Finding a series integration property is important before using other cointegration procedures, but this method does not require any pre-testing. The lag length of the variables can be used to resolve the endogeneity problem in the ARDL model. Second, it is applicable no matter how the series under study is integrated. Finally, the ARDL approach can produce accurate findings even with a small sample size. The specified model in equation (3) can be represented in equation (4) by ARDL bound testing approach. The following equation (4) makes it clear how the variables are related over a long time.

$$\Delta CO_{2t} = \alpha_0 + \alpha_1 CO_{2t-1} + \sum_{i=1}^{l} \alpha_1 \Delta EMT_{t-i} + \sum_{i=1}^{m} \alpha_2 \Delta EP_{t-i} + \sum_{i=1}^{o} \alpha_3 \Delta ENP_{t-i} + \sum_{i=1}^{q} \alpha_4 \Delta URB_{t-i} + \sum_{i=1}^{p} \alpha_5 \Delta GDP_{t-i} + \varepsilon_t \quad (4)$$

The short-run coefficients need to be obtained once the long-term relationships between variables are calculated. Equation (5) illustrates that to get the short-run parameters, the ECM must be computed.

$$\Delta CO_{2t} = \varphi_0 + \sum_{i=1}^{l} \varphi_1 \Delta CO_{2t-1} + \sum_{i=1}^{m} \varphi_2 \Delta EMT_{t-i} + \sum_{i=1}^{o} \varphi_3 \Delta EP_{t-i} + \sum_{i=1}^{q} \varphi_4 \Delta ENP_{t-i} + \sum_{i=1}^{p} \varphi_5 \Delta URB_{t-i} + \sum_{i=1}^{r} \varphi_5 GDP_{t-i} + \varepsilon_t \quad (5)$$

In Equations (4) and (5), l,m, p, o, r stand for the lag length of variables, ε_t stands for the disturbance term, whereas Δ in the first difference operator. The aforementioned equation also displays the dynamics of ECM and long-term connections between the series. Equation (2) is used to test the alternative and null hypotheses to determine whether the long-run connection exists or not. The final determination of the hypothesis is made using the estimated F-stat and comparing it with the critical value given by (Pesaran et al., 2001). We do not accept H0 when the measured statistical value surpasses the critical bound value of upper limit. It is supported whenever the calculated F-statistic is below the lower limit. H0 is not sufficiently rejected when the anticipated value is between the lower and upper values. Additionally, we assessed the optimal lag length using the AIC.

4. FINDINGS AND INTERPRETATIONS

First of all, unit root or stationarity tests are applied to estimate the integration order of the variables. For this purpose, two commonly used tests namely Augmented Dickey Fuller test (ADF) and Philips-Perron (PP) tests are applied in the current study. Finding the integration order of the series is necessary to apply appropriate techniques for developing long-term relationships between variables. The results of both tests are summarized in following Table 2. We find mixed order of integration among study variables.

4.1. ARDL Bound Test

After finding the order of integration, first of all optimal model is selected using AIC information criterion. After selecting the appropriate model, next we find either the study variables are cointegrated or not by applying ARDL Bound test (Pesaran et al., 2001). Table 3 reports the test results which reveal that long run cointegration exists among the series because the calculated F-statistic is higher than upper bound at all significance levels. So we established that all of the series are cointegrated, means there exist some long run relationship among them that needs to be investigated.

4.2. ARDL Long-run Estimation

After performing all necessary preliminary testing, now we proceed towards ARDL long run estimation. Table 4 provides us the corresponding results. First of all, EMT has negative impact on CO_2 emission in Indonesia in long run as its coefficient has statistically significant and negative value. This finding infers that a rise in EMT reduces environmental pollution and helps in

Table 1: Variable measurements and data sources

Variable of the study	Measurement	Data Source
CO_2 Emission	CO_2 Emission (metric tons per capita)	World development indicators
Environmental management	Patents in general environment management technologies	OECD
Environmental policy	Environmental policy stringency	OECD
Energy productivity	GDP per unit of TPES.	OECD
Economic Growth	GDP per capita growth (annual percentage)	World Development Indicators
Urbanization	Urban population (as percent of total population)	World Development Indicators

Table 2: Stationarity or unit root test findings

Variables or series	ADF		PP	
	I (1)	I (0)	I (1)	I (0)
CO2	−3.354***	----------	0.481	−5.235***
EMT	−2.296	−5.184***	−1.968	−8.739***
EP	−5.663	−3.829***	−2.081	−3.888***
ENP	−0.738	−4.135***	−0.441	−4.176***
URB	−2.796***	----------	−6.266***	---------
GDP	−3.645***	----------	−3.732***	---------

Table 3: ARDL bound results

Test statistics	Value	Significance level	Level	First difference	Decision
F-statistics	11.1834	10%	2.08	3	Cointegrated
K	5	5%	2.39	3.38	
		1%	3.06	4.15	

environmental sustainability in Indonesia. Previously the findings of Zhang et al. (2023), You et al. (2022) and Ahmad et al. (2021) strongly favour our findings as they also conclude that EMT has a major role in improving environmental quality by reducing pollution emissions. Moreover, EMT has major significance among all green innovation technologies (Zhang et al., 2023).

Second, the study finds significant and negative effect of energy productivity on carbon emission in Indonesia. The present findings support the fact that energy productivity is a viable tool for restricting CO_2 emissions in Indonesia. The finding is justifiable because energy productivity has successful limiting CO_2 emissions capabilities in several ways, such as increasing productivity, improving energy efficiency and reducing energy consumption. Energy productivity also improves energy efficiency by reducing costs and increases productivity. The findings of Wahab et al. (2021), Amin et al. (2022) and Ding et al. (2021) are strongly in line with our findings, who concluded the critical energy productivity role in decreasing CO_2 in respective countries. Therefore, developing and putting into practice energy productivity strategies can greatly reduce CO2 in Indonesia.

Third the outcome of long run estimation indicates the negative impact of environmental policy on CO_2 emission in the long run. The finding reveals that more strict environmental policies have favourable effect on mitigating environmental pollution in one of the highest emitting economies. This finding is consistent with Wang et al. (2020), Assamoi and Wang (2023) and Yirong (2022) as strict policies related to environment improve the quality by raising the polluting activity costs, promote businesses and firms to adopt ecologically-friendly technologies and projects. Additionally, strict environmental restrictions may raise public awareness and encourage people to change their consumption habits to be more environmentally friendly. More important of all, environmental policy stringency is associated with declining input prices of green technologies that can induce more investments in green technologies that ultimately reduce CO_2 emissions.

Fourth, the results of long run estimation reveal that GDP enhances CO_2 emissions in Indonesia, supporting the results of Liobikienė and Butkus (2019), Shahbaz et al. (2016) and Chien et al. (2023), who found the positive role of economic growth in increasing pollution emissions. This finding implies that when a country experiences quick and speedy economic growth, continuous activities can be observed in all of the economic sectors, including agriculture, manufacturing, allied industries and construction. As a consequence of these economic activities, the countries experience surge in non-renewable resources consumption, which generate harmful and polluting wastes and CO_2 emissions. And last, urbanization is also found to be associated with rising CO_2 emissions in Indonesia- finding consistent with the results of Zhang et al. (2017), Shahbaz et al. (2016) and Fan et al. (2020). The finding supports the fact that rapid urbanization is associated with higher demands for shelter, food, land use, transportation, energy use and raises concerns and issues for environmental quality such as waste management, traffic congestion, poor sanitation problems that cause health and pollution problems in urban areas (Shahbaz et al., 2017).

4.3. ARDL Short Run Analysis

ECM, which reflects the short-run dynamics, serves as the foundation for our short-run ARDL analysis. ECT has the coefficient that is statistically significant and negative, having a value <1, and thus satisfies all three requirements. The negative sign indicates that model reaches long-run equilibrium with a speed of 83%. Table 5 provides the short-run results. All the short-run parameters are significant at a 1% significance level. The short-run analysis shows that the variance in explanatory variables, which has an R^2 value of roughly 0.92 accounts for 92% of the variation in economic growth.

Table 4: ARDL long run results

DV (CO2)	Coeff	t-stat	P-value
DCO2	−1.743***	−3.008	0.0119
EMT	−0.033***	−3.399	0.0059
EP	−0.709***	−8.304	0.0000
ENP	−0.097***	−2.810	0.0000
GDP	0.0479**	6.177	0.0001
URB	0.0467***	2.537	0.0272
Cons	0.2654	0.619	0.5481

***P<0.05 and **P>0.05

Table 5: ARDL short run results

Variables	Coeff	t-stat	P-value
D (CO2)	−0.285***	−3.776	0.0031
D (EMT)	−3.530***	−5.067	0.0002
D (EP)	−0.313***	−3.803	0.0029
D (GDP)	0.007***	4.916	0.0005
D (URB)	1.007***	7.998	0.0000
D (ENP)	−1.747***	−2.987	0.0000
ECM	−0.839***	−10.999	0.0000
R^2 0.927			
Adj. R^2 0.888			

***P<0.05%

Table 6: Results of diagnostic test

Diagnostic Test	Test-value	Prob
Heteroskedasticity Test	1.295	0.337
Serial Correlation	10.25	0.480
Normality Test	0.945	0.623
Ramsey RESET Test	0.454	0.659

Figure 3: CUSUM plot

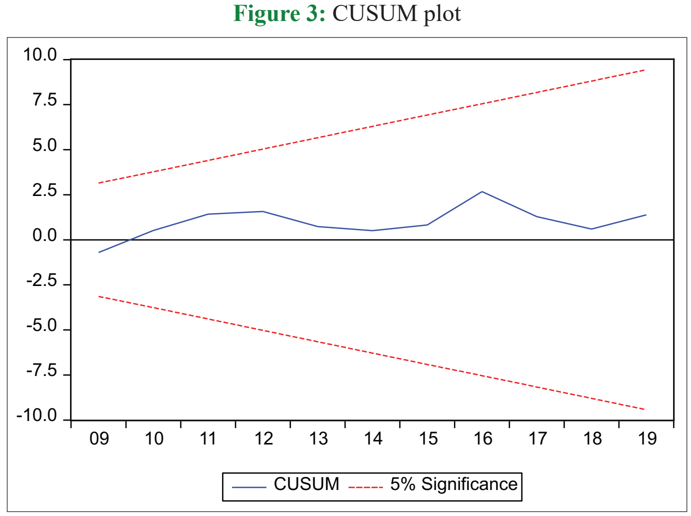
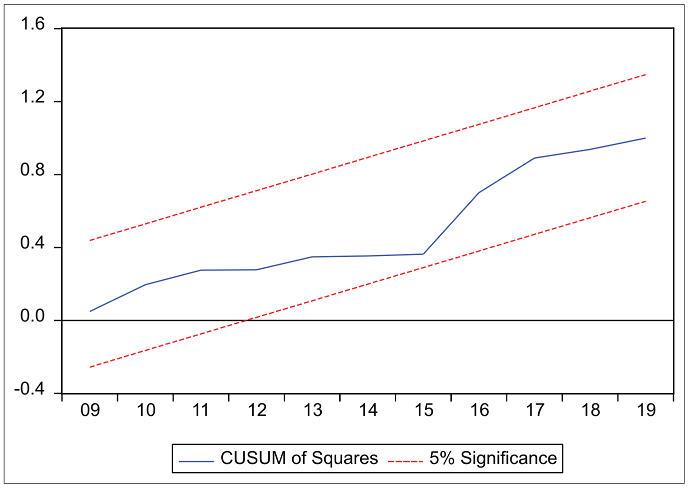


Figure 4: CUSUMSQ plot



4.4. Stability and Diagnostic Tests

Finally in Table 6 we present the diagnostic and stability tests. The CUSUM and CUSUM Square test graphs are given in Figures 3 and 4 respectively. The figures reveal that values fall under acceptable range at 5% level of significance which reveals the parameter's stability. Moreover the diagnostics test findings presented in Table 5 reveal that there is no heteroskedasticity and serial correlation problem and data is also normally distributed.

5. CONCLUSION AND POLICY RECOMMENDATIONS

Countries all over the world have realized that free market economies are associated with rising pollution emission and market forces failed in correcting the environmental degradation. Therefore, it is essential for the government to establish stringent laws and regulations that could assist preventative measures against environmental collapse. In addition, the rising carbon concentrations in the environment call for rapid collaboration between developed and developing countries to adopt several environmental management technologies. Keeping these facts into consideration, the basic objectives of the present study are to estimate the impact of environmental management, energy productivity and environmental policies on pollution emission in Indonesia. To that end, using STIRPAT model, collecting the data over 1990-2019 period and applying linear ARDL model, the study reach some important findings: First, we find that environmental policy stringency, environmental management technologies and energy productivity had positive impact on CO_2 emission. Second, urbanization and GDP are found to increase the environmental pollution in the long run and short run in Indonesia.

On the basis of the findings, some worthy policies are provided by the study. First, Indonesia should adopt strict environmental policies and legislations to mitigate environmental deterioration. Consumers and firms will be incentivized to adopt green technologies and ecologically friendly behavior by strict environmental policies and legislations. Second, as the findings suggest that environmental management technologies help reduce environmental pollutions, the Indonesian government should advocate for green technology policies that support environmental management. By providing green research and development expenditures, grants for green technologies start-ups, enhancing green business and investments, and raising demand for EMT, policymakers in Indonesia can support EMT applications. The government can also enhance EMT activities by using expenditure based strategies. Third, we suggest Indonesian government to design some worthy policies to encourage the energy productivity. Taking energy productivity as a target by policy makers would help in devising effective strategies for environmental quality improvement. For this purpose, Indonesian government should encourage the sectors having high energy productivity. In the residential and commercial sectors, policymakers are anticipated to use targeted programs and energy productivity strategies to lower market related and regulatory barriers. To achieve this, it would be necessary for everyone to work together to raise group investments in energy productivity initiatives that the government should fund.

5.1. Study Limitations and Directions for Future Studies

The study has significant theoretical and contextual contribution in the literature. However, like all studies, the present one is also not without its limitations. The study focuses on the role of environmental management and environmental policy on pollution emission. Future research studies can investigate the role of various management technologies like renewable energy technology, carbon capture and storage technologies and ICT related technologies in environmental quality. Moreover, along with environmental policy stringency, future researches can take into consideration the impact of carbon taxes and environmental taxes on pollution emission. Besides Indonesia, different countries or country blocs can also be taken into consideration by future researches. Methodologically, the present research estimates only linear impact of the variables on pollution emission, while future studies are recommended to explore non-linear impact of these variables not only on CO2 emission, but also on different pollution emission indicators like GHG, NO_2, SO_2 and CH_4 emissions.

REFERENCES

Abbasi, K.R., Oyebanji, M.O., Kirikkaleli, D. (2023), CO_2 intensity of GDP, energy productivity and environmental degradation in Iceland: Evidence from novel Fourier based estimators. Energy Sources, Part B: Economics, Planning, and Policy, 18(1), 2214906.

Addai, K., Kirikkaleli, D., Altuntaş, M. (2023), Energy productivity and environmental degradation in the Netherlands: Evidence from the novel Fourier-based estimators. Environmental Science and Pollution Research, 30, 75943-75956.

Afshan, S., Ozturk, I., Yaqoob, T. (2022), Facilitating renewable energy transition, ecological innovations and stringent environmental policies to improve ecological sustainability: Evidence from MM-QR method. Renewable Energy, 196, 151-160.

Afshan, S., Yaqoob, T., Meo, M.S., Hamid, B. (2023), Can green finance, green technologies, and environmental policy stringency leverage sustainability in China: Evidence from quantile-ARDL estimation. Environmental Science and Pollution Research, 30(22), 61726-61740.

Ahmad, M., Khan, Z., Rahman, Z.U., Khattak, S.I., Khan, Z.U. (2021), Can innovation shocks determine CO_2 emissions (CO_2e) in the OECD economies? A new perspective. Economics of Innovation and New Technology, 30(1), 89-109.

Albulescu, C.T., Boatca-Barabas, M.E., Diaconescu, A. (2022), The asymmetric effect of environmental policy stringency on CO_2 emissions in OECD countries. Environmental Science and Pollution Research, 29(18), 27311-27327.

Al-Maamary, H.M., Kazem, H.A., Chaichan, M.T. (2017), Climate change: The game changer in the Gulf Cooperation Council region. Renewable and Sustainable Energy Reviews, 76, 555-576.

Alola, A.A., Joshua, U. (2020), Carbon emission effect of energy transition and globalization: inference from the low-, lower middle-, upper middle-, and high-income economies. Environmental Science and Pollution Research, 27(30), 38276-38286.

Amin, M., Zhou, S., Safi, A. (2022), The nexus between consumption-based carbon emissions, trade, eco-innovation, and energy productivity: Empirical evidence from N-11 economies. Environmental Science and Pollution Research, 29(26), 39239-39248.

Anwar, M., Fayyaz, A., Sohail, N., Khokhar, M., Baqar, M., Khan, W., Nizami, A. (2018), CO_2 capture and storage: A way forward for sustainable environment. Journal of Environmental Management, 226, 131-144.

Assamoi, G.R., Wang, S. (2023), Asymmetric effects of economic policy uncertainty and environmental policy stringency on environmental quality: Evidence from China and the United States. Environmental Science and Pollution Research, 30(11), 29996-30016.

Aubrée, R., Auger, F., Macé, M., Loron, L. (2016), Design of an efficient small wind-energy conversion system with an adaptive sensorless MPPT strategy. Renewable Energy, 86, 280-291.

Baloch, M.H., Wang, J., Kaloi, G.S. (2016), Stability and nonlinear controller analysis of wind energy conversion system with random wind speed. International Journal of Electrical Power and Energy Systems, 79, 75-83.

Baloch, Z.A., Tan, Q., Kamran, H.W., Nawaz, M.A., Albashar, G., Hameed, J. (2021), A multi-perspective assessment approach of renewable energy production: Policy perspective analysis. Environment, Development and Sustainability, 24, 1-29.

Chen, M., Sohail, S., Majeed, M.T. (2022), Revealing the effectiveness of environmental policy stringency and environmental regulation on environmental performance: Does asymmetry matter? Environmental Science and Pollution Research, 29, 91190-91200.

Chien, F., Chau, K.Y., Sadiq, M. (2023), Impact of climate mitigation technology and natural resource management on climate change in China. Resources Policy, 81, 103367.

Chien, F., Hsu, C.C., Moslehpour, M., Sadiq, M., Tufail, B., Ngo, T.Q. (2023), A step toward sustainable development: The nexus of environmental sustainability, technological advancement and green finance: Evidence from Indonesia. Environment, Development and Sustainability, 29, 1-22.

Chien, F., Sadiq, M., Kamran, H.W., Nawaz, M.A., Hussain, M.S., Raza, M. (2021), Co-movement of energy prices and stock market return: Environmental wavelet nexus of COVID-19 pandemic from the USA, Europe, and China. Environmental Science and Pollution Research, 28(25), 32359-32373.

Chien, F., Sadiq, M., Nawaz, M.A., Hussain, M.S., Tran, T.D., Le Thanh, T. (2021), A step toward reducing air pollution in top Asian economies: The role of green energy, eco-innovation, and environmental taxes. Journal of Environmental Management, 297, 1-11.

Choi, B., Park, W., Yu, B.K. (2017), Energy intensity and firm growth. Energy Economics, 65, 399-410.

Dietz, T., Rosa, E.A. (1994), Rethinking the environmental impacts of population, affluence and technology. Human Ecology Review, 1(2), 277-300.

Ding, Q., Khattak, S.I., Ahmad, M. (2021), Towards sustainable production and consumption: Assessing the impact of energy productivity and eco-innovation on consumption-based carbon dioxide emissions (CCO_2) in G-7 nations. Sustainable Production and Consumption, 27, 254-268.

Dogan, E., Hodžić, S., Fatur Šikić, T. (2022), A way forward in reducing carbon emissions in environmentally friendly countries: The role of green growth and environmental taxes. Economic research-Ekonomska Istraživanja, 35(1), 5879-5894.

Fan, H., Hashmi, S.H., Habib, Y., Ali, M. (2020), How do urbanization and urban agglomeration affect CO_2 emissions in South Asia? Testing non-linearity puzzle with dynamic STIRPAT model. Chinese Journal of Urban and Environmental Studies, 8(01), 2050003.

Fethi, S., Rahuma, A. (2020), The impact of eco-innovation on CO_2 emission reductions: Evidence from selected petroleum companies. Structural Change and Economic Dynamics, 53, 108-115.

Galeotti, M., Salini, S., Verdolini, E. (2020), Measuring environmental policy stringency: Approaches, validity, and impact on environmental innovation and energy efficiency. Energy Policy, 136, 111052.

Hafeez, M., Rehman, S.U., Faisal, C.N., Yang, J., Ullah, S., Kaium, M.A., Malik, M.Y. (2022), Financial efficiency and its impact on renewable energy demand and CO_2 emissions: Do eco-innovations matter for highly polluted Asian economies? Sustainability, 14(17), 10950.

Hanif, S., Nawaz, M.A., Fazal, S., Ibraheem, R. (2022), Role of natural resources and eco-innovations in determination of the environmental quality of Pakistan: Evidence through vector autoregressive (VAR) estimation. iRASD Journal of Economics, 4(1), 127-140.

Haq, M.A.U., Nawaz, M.A., Akram, F., Natarajan, V.K. (2020), Theoretical implications of renewable energy using improved cooking stoves for rural households. International Journal of Energy Economics and Policy, 10(5), 546-557.

Hashmi, R., Alam, K. (2019), Dynamic relationship among environmental regulation, innovation, CO_2 emissions, population, and economic growth in OECD countries: A panel investigation. Journal of Cleaner Production, 231, 1100-1109.

Hordofa, T.T., Vu, H.M., Maneengam, A., Mughal, N., Liying, S. (2023), Does eco-innovation and green investment limit the CO_2 emissions in China? Economic research-Ekonomska Istraživanja, 36(1), 634-649.

Huaman, R.N.E., Jun, T.X. (2014), Energy related CO_2 emissions and the progress on CCS projects: A review. Renewable and Sustainable Energy Reviews, 31, 368-385.

Hussain, M.S., Nawaz, M.A., Ahmad, T.I., Bhatti, M.A. (2021), Environmental governance and green energy: An administrative toolkit to reduce environmental degradation. iRASD Journal of Management, 3(3), 329-338.

Kamoun, M., Abdelkafi, I., Ghorbel, A. (2019), The impact of renewable energy on sustainable growth: Evidence from a panel of OECD countries. Journal of the Knowledge Economy, 10, 221-237.

Khan, S., Alvarado, R., Nawaz, M.A., Ahmed, Z., Rehman, A., Elahi, S.M. (2023), Determinants of environmental quality in India: evidence using the bootstrapped ARDL model with structural breaks. Environmental Science and Pollution Research, 30, 64651-64661.

Kirikkaleli, D., Karmoh Sowah, J. Jr., Addai, K. (2023), The asymmetric and long-run effect of energy productivity on environmental quality in Ireland. Environmental Science and Pollution Research, 30(13), 37691-37705.

Kumar, M., Sundaram, S., Gnansounou, E., Larroche, C., Thakur, I.S. (2018), Carbon dioxide capture, storage and production of biofuel and biomaterials by bacteria: A review. Bioresource Technology, 247, 1059-1068.

Leung, D.Y., Caramanna, G., Maroto-Valer, M.M. (2014), An overview of current status of carbon dioxide capture and storage technologies. Renewable and Sustainable Energy Reviews, 39, 426-443.

Lin, B., Zhu, J. (2019), The role of renewable energy technological innovation on climate change: Empirical evidence from China. Science of the Total Environment, 659, 1505-1512.

Liobikienė, G., Butkus, M. (2019), Scale, composition, and technique effects through which the economic growth, foreign direct investment, urbanization, and trade affect greenhouse gas emissions. Renewable Energy, 132, 1310-1322.

Liu, Z., Lan, J., Chien, F., Sadiq, M., Nawaz, M.A. (2022), Role of tourism development in environmental degradation: A step towards emission reduction. Journal of Environmental Management, 303, 114-128.

Mohsin, M., Kamran, H.W., Nawaz, M.A., Hussain, M.S., Dahri, A.S. (2021), Assessing the impact of transition from nonrenewable to renewable energy consumption on economic growth-environmental nexus from developing Asian economies. Journal of Environmental Management, 284, 1-11.

Nawab, T., Bhatti, M.A., Nawaz, M.A. (2021), Does technological innovation advance environmental sustainability in ASEAN Countries? Pakistan Journal of Humanities and Social Sciences, 9(3), 425-434.

Nawaz, M.A., Ahmadk, T.I., Hussain, M.S., Bhatti, M.A. (2020), How energy use, financial development and economic growth affect carbon dioxide emissions in selected association of south east asian nations. Paradigms, SI (1), 159-165.

Oyebanji, M.O., Kirikkaleli, D. (2022), Energy productivity and environmental deregulation: The case of Greece. Environmental Science and Pollution Research, 29(55), 82772-82784.

Pachauri, R.K., Allen, M.R., Barros, V.R., Broome, J., Cramer, W., Christ, R., &. Dasgupta, P. (2014), Climate Change 2014: Synthesis report. Contribution of Working Groups I, II and III to the Fifth Assessment report of the Intergovernmental Panel on Climate Change. Switzerland: IPCC.

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.

Pigou, A.C. (1920), Some problems of foreign exchange. The Economic Journal, 30(120), 460-472.

Rej, S., Bandyopadhyay, A., Das, N., Hossain, M.E., Islam, M.S., Bera, P., Yeediballi, T. (2023), The asymmetric influence of environmental-related technological innovation on climate change mitigation: What role do FDI and renewable energy play? Environmental Science and Pollution Research, 30(6), 14916-14931.

Salvia, M., Reckien, D., Pietrapertosa, F., Eckersley, P., Spyridaki, N.A., Krook-Riekkola, A., Geneletti, D. (2021), Will climate mitigation ambitions lead to carbon neutrality? An analysis of the local-level plans of 327 cities in the EU. Renewable and Sustainable Energy Reviews, 135, 110253.

Santra, S. (2017), The effect of technological innovation on production-based energy and CO2 emission productivity: Evidence from BRICS countries. African Journal of Science, Technology, Innovation and Development, 9(5), 503-512.

Sezgin, F.H., Bayar, Y., Herta, L., Gavriletea, M.D. (2021), Do environmental stringency policies and human development reduce CO_2 emissions? Evidence from G7 and BRICS economies. International Journal of Environmental Research and Public Health, 18(13), 6727.

Shah, A.A., Hussain, M.S., Nawaz, M.A., Iqbal, M. (2021), Nexus of renewable energy consumption, economic growth, population growth, FDI, and environmental degradation in south asian countries: New evidence from Driscoll-Kraay standard error approach. iRASD Journal of Economics, 3(2), 200-211.

Shahbaz, M., Chaudhary, A., Ozturk, I. (2017), Does urbanization cause increasing energy demand in Pakistan? Empirical evidence from STIRPAT model. Energy, 122, 83-93.

Shahbaz, M., Loganathan, N., Muzaffar, A.T., Ahmed, K., Jabran, M.A. (2016), How urbanization affects CO_2 emissions in Malaysia? The application of STIRPAT model. Renewable and Sustainable Energy Reviews, 57, 83-93.

Shair, F., Shaorong, S., Kamran, H.W., Hussain, M.S., Nawaz, M.A., Nguyen, V.C. (2021), Assessing the efficiency and total factor productivity growth of the banking industry: Do environmental concerns matters? Environmental Science and Pollution Research, 28(16), 20822-20838.

Sinha, A., Sengupta, T., Saha, T. (2020), Technology policy and environmental quality at crossroads: Designing SDG policies for select Asia Pacific countries. Technological Forecasting and Social Change, 161, 120317.

Sohail, A., Du, J., Abbasi, B.N., Ahmed, Z. (2022), The nonlinearity and nonlinear convergence of CO_2 emissions: Evidence from top 20 highest emitting countries. Environmental Science and Pollution Research, 29(39), 59466-59482.

Wahab, S., Zhang, X., Safi, A., Wahab, Z., Amin, M. (2021), Does energy productivity and technological innovation limit trade-adjusted carbon emissions? Economic research-Ekonomska Istraživanja, 34(1), 1896-1912.

Wang, K., Yan, M., Wang, Y., Chang, C.P. (2020), The impact of environmental policy stringency on air quality. Atmospheric Environment, 231, 117522.

Wang, Z., Yen-Ku, K., Li, Z., An, N.B., Abdul-Samad, Z. (2022), The transition of renewable energy and ecological sustainability through environmental policy stringency: Estimations from advance panel estimators. Renewable Energy, 188, 70-80.

Wolde-Rufael, Y., Mulat-Weldemeskel, E. (2021), Do environmental taxes and environmental stringency policies reduce CO_2 emissions? Evidence from 7 emerging economies. Environmental Science and Pollution Research, 28, 22392-22408.

Wolde-Rufael, Y., Weldemeskel, E.M. (2020), Environmental policy stringency, renewable energy consumption and CO_2 emissions: Panel cointegration analysis for BRIICTS countries. International Journal of Green Energy, 17(10), 568-582.

Xin, D., Ahmad, M., Khattak, S.I. (2022), Impact of innovation in climate change mitigation technologies related to chemical industry on carbon dioxide emissions in the United States. Journal of Cleaner Production, 379, 134746.

Yirong, Q. (2022), Does environmental policy stringency reduce CO_2 emissions? Evidence from high-polluted economies. Journal of Cleaner Production, 341, 130648.

York, R., Rosa, E.A., Dietz, T. (2004), The ecological footprint intensity of national economies. Journal of Industrial Ecology, 8(4), 139-154.

You, C., Khattak, S.I., Ahmad, M. (2022), Do international collaborations in environmental-related technology development in the US pay off in combating carbon dioxide emissions? Role of domestic environmental innovation, renewable energy consumption, and trade openness. Environmental Science and Pollution Research, 29, 1-21.

Yuan, R., Li, C., Ahmed Memon, J., Ali, M., Nawaz, M.A. (2022), The nexus between fiscal decentralization and environmental sustainability in Japan. Frontiers in Environmental Science, 10, 905461.

Zhang, N., Yu, K., Chen, Z. (2017), How does urbanization affect carbon dioxide emissions? A cross-country panel data analysis. Energy Policy, 107, 678-687.

Zhang, X., Shi, X., Khan, Y., Hassan, T., Marie, M. (2023), Carbon neutrality challenge: Analyse the role of energy productivity, renewable energy, and collaboration in climate mitigation technology in OECD economies. Sustainability, 15(4), 3447.