*Pol. J. Environ. Stud. Vol. XX, No. X (XXXX), 1-14*
DOI: *10.15244/pjoes/200221* ONLINE PUBLICATION DATE:

*Original Research*

# Driving the Green Shift: How Energy Transition and Environmental Policy Stringency Shape Environmental Quality

**Muhammad Asghar Khan[1], Pomi Shahbaz[2], Uyen Pham Thi Minh[3]*, Ngoc Hung Nguyen[4], Thanh Huyen Mai[5]**

[1]School of Economics and Management, Panzhihua University, Panzhihua, China
[2]Department of Economics, Division of Management and Administrative Science, University of Education Lahore, Pakistan
[3]Faculty of Mathematical Economics, Thuongmai University, Hanoi, Viet Nam
[4]Institute of Business Administration Thuongmai University, Hanoi, Viet Nam
[5]Faculty of International Business and Economics, Thuongmai University, 79 Ho Tung Mau, Hanoi, Vietnam

*Received: 9 October 2024*
*Accepted: 17 January 2025*

**Abstract**

Climate change and environmental degradation pose serious threats to socio-economic and ecological development. Global economies enforce strict environmental regulations and renewable energy transition policies to address climate vulnerability. Therefore, this study aimed to explore the moderating role of environmental policy stringency (EPS) on the relationship between energy transition (ET) and carbon dioxide ($CO_2$) emissions from energy. The present study also aims to examine the effects of energy transition and environmental stringency policies on $CO_2$ emissions from energy. For this purpose, this study utilized a cross-sectional autoregressive distributional lag approach on panel data (1995-2020) from 38 world economies. Moreover, two econometric techniques, augmented mean group (AMG) and common correlated effects mean group (CCEMG), were used for the robustness checks. The findings revealed that ET and EPS have significant and negative individual impacts on $CO_2$ emissions. Similarly, EPS also plays a strong moderating role in the relationship between ET and $CO_2$ emission. This implies that EPS can boost ET, which plays a crucial role in lowering $CO_2$ emissions and improving environmental quality. Policymakers should support investment in renewable energy transitions, offer fiscal incentives to the sector, and nurture competitive market structures that provide policy direction and expectations for the renewed energy business.

**Keywords:** energy transition, renewable energy, environmental degradation, environmental policy, environmental quality

*e-mail: uyenptm@tmu.edu.vn

## Introduction

Environmental degradation is the most serious threat faced by the contemporary world today [1]. Global warming and increased $CO_2$ emissions lead to pressure on the environment and the life of living organisms. Climate change hazards are caused by increased $CO_2$ emissions and escalating atmospheric pollutant emissions [2]. Therefore, it is believed that climate change constitutes a real threat to human life, and this occurs by adding continuous pollution to the atmosphere without considering its effects. Furthermore, the environment has continuously deteriorated due to increasing global productivity, faster population growth, and increased energy consumption. Environmental agreements regarding global warming and environmental protection have been signed in recent years, such as the Kyoto Protocol signed in 1997 and the Conference of the Paris (COP21) held in 2015 [3]. This includes an action plan to achieve zero carbon emissions in several countries worldwide. Countries are implementing several strategies to counterbalance carbon emissions in ways that will ensure a shift from carbon emissions.

Energy consumption is one of the primary factors affecting a country's security and socio-economic development. The conscious and effective promotion of renewable energy (RE) has become a major strategic concern and a global process for transitioning energy systems and environmental protection. As estimated from projections, RE generation in the world is projected to increase by more than 75% between 2022 and 2027 [4]. Large economies and continents increasingly seek to enhance their efforts toward managing climate change, thus initiating a tremendous increase in RE deployment. Specifically, in electricity generation, the use of RE not only reduces dependency on scarce resources and pollution in the environment but also establishes equilibrium in environmental factors and enhances environmentally friendly energy and energy changes. This makes it easier to address the challenges of climate change, reduction of greenhouse products, energy scarcity, and environmental degradation.

In various ways and through different degrees of commitment attained internationally, environmental deterioration does not cease, and $CO_2$ emissions continue to increase. The power sector is one of the highest emitters of carbon pollutants. The increase can be mainly due to the much higher utilization of non-renewable resources to generate electricity to cope with rising demand. The $CO_2$ emissions of this sector stood at 1.46 billion, attaining their historical peak [5]. Therefore, to eliminate the severity of poor carbon emissions, a shift in power production must occur instantly to shift from fossil fuels to RE resources. Using RE sources leads to near-zero or no emissions of GHGs, thereby effectively eliminating carbon output [6]. However, the combustion processes involved in fossil fuels release large amounts of greenhouse gasses (GHGs), especially carbon dioxide, contributing to climate change [7]. RE comes from naturally replenishing resources and eliminating depletion issues, unlike fossil fuels, which are limited and exhausting. Therefore, swapping cleaner energy sources for electricity generation may advance the quest for ES. However, the major trend among various RE sources depends more on policies that are supportive in nature. By setting goals and objectives through policies, we observe that governments have the ability to influence the strategic direction of RE, thus driving a change towards a low-carbon energy system.

Nonetheless, it is important to understand that advances in energy accessibility are not consistent and have differences in different world regions [8]. Therefore, achieving an extensive energy shift is still in the future and can only be realized through international cooperation. The authors highlighted energy transition (ET) as a solution to prevent environmental degradation [9]. As many countries have legislated on environmental sustainability (ES), unavoidably, industrialized countries maintain the highest mean level of greenhouse gas emissions to the present moment [10].

Environmental policies remain an essential form of ecological governance because they play a central role in the search for ecological sustainability. Currently, most countries are implementing various governance systems to reduce carbon output. Such approaches include technology [11], innovation [12], fiscal [13], and energy [14] policies, and more importantly, regulations on $CO_2$ emissions. Today, the largest number of countries have relevant policies, including subsidies, taxes, and other fiscal measures. The aforementioned fiscal policies have different levels of effectiveness in reducing $CO_2$ emissions. Studies have shown the great potential of ecological governance as a solution for carbon emission reduction. Zhou et al. [14] also argue that ecological restoration increases the sequestration capacity for carbon in a region, further increasing the carbon stock in the ecosystems. Zen et al. [15] considered climate adaptation measures to achieve multi-level climate governance.

Thus, it is critical to design a policy framework that would reform existing energy regulations to optimize the consideration of the environmental question. The rationale behind this argument is the need for policy improvement in nations to foster climate management by modifying environmental rules to conform to sustainable development goals. This situation indicates that the global Sustainable Development Goals (SDGs) provide a comprehensive framework necessary to fulfill the goals set by 2030. Therefore, applying this analytical framework is essential because of the existing synergy between the economy and the environment and efforts towards sustainable development in the world. However, the current literature corpus has several limitations. In this discussion, the key focus is on developed countries, along with their heightened sensitivity to the effects of change within the environment. These countries are expected to experience the heat of repercussions from other factors due to global warming. In addition, rising economic growth means higher energy use, which emits higher pollutants that significantly threaten human beings and the environment. SDG 7 requires utility, low-cost, and clean energy.

To increase the policy impact in countries and improve its function, regulators and policymakers should clearly define the position of environmental policies in energy transition (ET). This will enhance the formulation of better ways to encourage sustainability and counter the impacts of GHG emissions. Thus, there is a need to emphasize meaningful, influential aspects that help policymakers achieve the SDGs. Tight environmental laws are the primary precondition for developing stable environmental policies that are necessary for the transition to green energy. This argument supports the need for proper regulation that can be aligned with the environmental policies necessary to enhance the achievement of SDGs (7, 13). Therefore, this study aims to advance existing knowledge by exploring the moderating role of environmental policy stringency (EPS) on the relationship between ET and $CO_2$ emissions from energy by demonstrating the capability of environmental policy and law in fostering the complementary aims of sustainable development. Moreover, the present study also aims to examine the effect of energy transition and environmental stringency policy on $CO_2$ emissions from energy. This study sheds light on the following two research questions:

i) Do ET and EPS have the potential to curtail $CO_2$ emissions from energy?

ii) To what degree does the implementation of EPS moderate the association between ET and $CO_2$ emissions from energy?

## Literature Review

### Energy Transition and $CO_2$ Emissions

Empirical literature measures environmental quality through $CO_2$ emissions or $CO_2$ efficiency. Several studies have reviewed the factors affecting $CO_2$ emissions in both developed and developing countries. Some of these studies have employed ET as the primary reason for environmental quality.

The effects of the ET on $CO_2$ emissions are analyzed in terms of two fundamental components referred to as the 'substitution effect' and the 'technology base effect.' The substitution effect indicates that the rise of RE sources supplies fossil energy sources, leading to efficient energy utilization and reduced $CO_2$ emissions [16]. In turn, the validity of the substitution effect was illustrated by Shafiei and Salim [17], who established that non-RE increases the level of $CO_2$ emissions while RE decreases $CO_2$ emissions. Bilgili et al. [18] established a negative relationship between RE consumption and the level of $CO_2$ emissions. Similarly, Ertugrul et al. [19] found that RE deployment reduced $CO_2$ emissions in developed and developing nations. Dong et al. [20] stated that a significant negative relationship exists between RE and $CO_2$ emissions in low- and middle-income countries, as well as high-income economies.

Similarly, Ahmad and Satrovic [21] gauged the efficiency of RE on the ecological environment in OECD countries, along with the reduction in carbon intensity and footprints. Sharifzadeh et al. [22] also proposed substituting fossil fuels with RE sources (such as wind and solar) and integrating renewables into grid transformation for a marked improvement in both carbon and atmospheric pollution. These studies have invariably supported the importance of ET in decreasing carbon and maintaining the environment. On the other hand, ET is a process that must be set for sustainable development to be realized [23]. Sustainable development is divided into three categories: economic, social, and environmental. ET ensures the greatest integration of these three. First, the shift to clean and RE will help decrease reliance on traditional energy sources, thus improving energy security [24]. According to Wang et al. [25], the use of RE can substantially decrease the utilization of fossil fuels, thereby contributing greatly to the country's energy security. Second, clean and RE sources not only contribute to positive economic development but also promote energy efficiency and reduce environmental impacts [26]. RE investment, energy efficiency, and climate risks were investigated by Guo et al. [27], who explained that RE investment has a positive impact as it enhances the efficiency of energy and minimizes the occurrence of climate disasters.

Kahia et al. [28] found that using RE effectively reduces $CO_2$ emissions. In addition, Bilgili et al. [18] addressed the data of 17 OECD member countries and observed that RE consumption and $CO_2$ emissions are short- and long-run cointegrated, with negative long-run relationships; thus, they recommended increasing the use of RE to reduce $CO_2$ emissions. Finally, clean and RE sources improve the quality of life and promote positive social change [29].

Technology-based effect postulates that RE causes environmental deterioration. This impact is because RE installation involves a large initial investment, highly skilled personnel (human capital), and complex technology that requires environmental space and technical support [30, 31]. The supply of electricity through renewable sources requires support from fossil sources to meet the peak loads. Because there is a lack of a storage system for energy, RE supply could be inconsistent [32]. As a result, the substitution effect, RE replacing fossil fuels and lowering $CO_2$ emissions, may be constrained. According to findings, the exogenous technology effect may surpass the home technology substitution effect in certain nations [33]. For example, Yurtkuran [34] pointed out that rising RE production led to higher $CO_2$ emissions in Turkey from 1970 to 2017, indicating that Turkey was in the technology-based effect more strongly in the concerned period.

Some scholars believe that ETs do not necessarily enhance ES and may even worsen environmental problems. For instance, Wang et al. [35] established curvilinear interactions between renewables and emissions and pointed out that diverse effects exist and that renewables may not eliminate carbon emissions in regions where the rate of electricity consumption expands relatively quickly. Satrovic and Adedoyin [36] also stressed that shifts in the structure of RE sources could lead to new levels of environmental unfriendliness rather than reducing emissions.

## Environmental Policy Stringency and $CO_2$ Emissions

EPS refers to the extent and intensity of the policies set by the government and is adopted to prevent and minimize environmental pollution, especially focusing on carbon dioxide emissions [37]. Environmental regulations affect firm goals and requirements to help lower the emissions of $CO_2$ [38]. These policies include emission standards, carbon prices, RE subsidies, and industrial emissions restrictions. Through these regulations, governments want industries and people to adopt clean technologies, reduce energy usage, and minimize carbon emissions [39]. In this way, industries are forced to spend more on efficient and cleaner technology and practice development, enhancing technological and efficiency advancement. This, in turn, helps to apply energy-efficient processes and RE and cleaner production methods [40]. In addition, stringent environmental laws alert people to the consequences of $CO_2$ emissions on the environment. This awareness leads to changes in practices and behaviors at individual and collective levels, such as energy saving and carbon footprint control, as well as support for sustainable activities [41]. Collective action, in which people and populations participate in decreasing $CO_2$ emissions, has a comprehensive effect. As firms face additional regulation, they might alleviate pollution by upgrading from "polluting" to "non-polluting" technology. Based on the aforementioned theoretical framework, Du et al. [42] opined that the high stringency of environmental regulation may reduce the detrimental impact on $CO_2$ emissions through technology and innovation.

Godawska & Wyrobek [43] address the effects of EPS on RE, postulating that it can potentially significantly encourage the development of renewable energies and the replacement of non-renewable energies. Wang et al. [44] studied the EPS impacts on the ET in BRICS nations between 1990 and 2019. Their results confirmed a long-run relationship between $CO_2$ emissions and EPS, along with the short-run effects of RE resource consumption. Examining the modulating influence of EPS on green finance in China. Alsagr and van Hemmen [37] explained the response of RE investment to positive shocks in EPS and established that, for all quantiles, RE investment rises in the short and long run. On the other hand, negative shocks to EPS decreased RE investment at the lower and medium quantiles of EPS. Therefore, Ren and Pei [45] investigated the nexus between green finance and EPS policies with REC in China. They found that positive shocks in both green finance and EPS raise RE consumption. On the contrary, negative shocks have a distinct effect because they significantly contribute to the non-achievement of ET goals by reducing RE consumption in the future.

Fuinhas et al. [46] explored the relationship between RE policies and $CO_2$ emissions using a PNARDL model. The authors have a different view and simultaneously provide information that $CO_2$ reduction is associated with the effectiveness of RE policies to stimulate the use of new types of energy in the electricity industry. Other scholars have held this view [17, 47]. The second stream of literature states that the increased consumption of RE leads to increased emissions [48, 49]. Koengkan et al. [50] investigated the relationship between hydroelectricity consumption and $CO_2$ emissions in seven countries in South America from 1966-2014. The results showed that applying a given type of energy resulted in augmented emissions in the long run. Indeed, this effect takes place immediately after the creation of a reservoir when the trees that have died in the process of flooding release $CO_2$ in their decomposition process or from turbines and spillways in the energy generation process. These emissions can be compared with those that fossil fuels may produce.

# Materials and Methods

Energy is a major source of environmental degradation. Therefore, $CO_2$ emissions from different energy sources were the dependent variables in our study. RE has a lower environmental impact than that of fossil fuels. ET indicates the transformation of energy sources from carbon-intensive to renewable. Moreover, ET describes the dependency level of countries on fossil fuels, the level of energy sector decarbonization, and the adoption of energy-efficient technologies. Therefore, the current study used ET as the first important independent variable, which was measured by RE consumption divided by total energy consumption. Policies are an effective tool for governments to direct economic activities toward sustainable development. The strict implementation of policies can transform the behavior of economic agents toward a sustainable environment. Moreover, environmentally oriented policies may be directed toward sustainable production and consumption of energy. Therefore, EPS was included as the second most important independent variable. Additionally, EPS was also included in the model as a moderator between the relationship between ET and $CO_2$ emissions. Considering the impact of economic growth on $CO_2$ emissions, GDP per capita was included in the study as an independent variable because an increase in GDP is expected to demand high energy, leading to more $CO_2$ emissions. Urbanization (URB) is also an important aspect of economic development that majorly contributes to environmental quality. Moreover, an increase in URB may increase the demand for high energy, necessitating the inclusion of URB as an independent variable. The industry of an economy is also a major consumer of energy, and the industry structure (IS), in terms of expansion, signifies the importance of analyzing its impact on $CO_2$ emissions. IS was measured using three different indicators, the weights of which were measured using the entropy model to combine the indicators (Table 1).

The general functional form (Eq. 1) is given below, presenting the $CO_2$ emission as a function of all the earlier-mentioned variables.

$$CO_{2_{it}} = f(GDP_{it}, ET_{it}, EPS_{it}, URB_{it}, IS_{it}) \quad (1)$$

As EPS can moderate the impact of ET on $CO_2$ emissions, an interaction term (ET*EPS) was added to Eq. (1) to analyze this impact, as given below.

$$CO_{2_{it}} = f(GDP_{it}, ET_{it}, EPS_{it}, (ET_{it} * EPS_{it}), URB_{it}, IS_{it}) \quad (2)$$

To stabilize the variance and analyze the relative change in variables, we first transformed the $CO_2$ emissions, GDP per capita, and URB and then included them in the model. However, ET, EPS, and IS were not transformed because these variables were already proportional and index variables. Moreover, the direct impact rather than relative change may facilitate the interpretation. Therefore, the original model was written as

$$lnCO_{2_{it}} = \beta_o + \beta_1 lnGDP_{it} + \beta_2 ET_{it} + \beta_3 lnEPS_{it} + \beta_4 lnURB_{it} + \beta_5 IS_{it} + e_{it} \quad \text{(M-1)}$$

Similarly, (M-1) was further transformed by including the interaction term ($ET_{it} * EPS_{it}$).

$$lnCO_{2_{it}} = \gamma_o + \gamma_1 lnGDP_{it} + \gamma_2 ET_{it} + \gamma_3 lnEPS_{it} + \gamma_4 (ET_{it} * EPS_{it}) + \gamma_5 lnURB_{it} + \gamma_6 IS_{it} + \varphi_{it} \quad \text{(M-2)}$$

where (M-1) and (M-2) indicate that β and γ are unknown parameters to be estimated through proper econometric techniques, and $e_{it}$ and $\varphi_{it}$ signify the error terms of the respective model.

## Data

The study analyzes the impact of independent variables on $CO_2$ emissions from energy sources. For this purpose, data on the dependent variable is obtained from https://www.eia.gov/, where data on $CO_2$ emissions from energy sources is openly available. Data on the variables used for measuring the ET and IS, GDP per capita, and URB were collected from World Development Indicators (WDI) https://databank.worldbank.org/; EPS data were downloaded from OECD Environment statistics. Data from 38 different economies for 26 years from 1995 to 2020 were used to perform the econometric analysis. Table 2 provides detailed information on these variables.

## Estimation Techniques

First, a descriptive analysis was performed to summarize the variables. The standard deviation was measured to examine the variables' volatility. The Jarque-Bera normality test [51] was used to examine the variables' normality, skewness, and kurtosis. The following Eq. (3) presents the general form of the Jarque and Bera normality test (JBN).

$$\text{JBN} = \frac{N}{6}\left(S^2 + \frac{(K-3)^2}{4}\right) \quad (3)$$

where N is the degree of freedom, and S and K indicate skewness and kurtosis, respectively. Next, a slope heterogeneity test was performed to examine the assumptions of slope heterogeneity. Two different techniques were used, $\hat{\Delta}$ and adj. $\hat{\Delta}$ was proposed by Pesaran and Yamagata [52].

$$\hat{\Delta} = \sqrt{N(2k)^{-1}}(N^{-1}S' - K) \quad (4)$$

$$\text{adj. } \hat{\Delta} = \sqrt{N}\sqrt{\frac{T+1}{2K(T-K-1)}}(N^{-1}S' - 2K) \quad (5)$$

In Eq. (4) and Eq. (5), $\hat{\Delta}$ indicates slope heterogeneity and adj. $\hat{\Delta}$ presents the adjusted slope heterogeneity. After confirming the slope heterogeneity assumption,

Table 1. Indicators of industrial structure.

| Indicators | Description | Units | Source |
|---|---|---|---|
| Industrial sector contribution | Industrial sector share in GDP, indicating the size and importance of the industry | % of GDP | WDI |
| Manufacturing contribution | Contribution of the manufacturing sector within the broader industry | % of GDP | WDI |
| Trade dimension | Export of goods and services | % of GDP | WDI |

Table 2. Variable's source and units.

| Variables | Acronyms | Units | Source |
|---|---|---|---|
| Carbon dioxide emission from energy | $CO_2$ | MMTCD | EIA |
| Energy Transition | ET | Renewable energy consumption/ Total energy consumption (%) | WDI |
| Environmental policy stringency | EPS | Index | OECD Library |
| GDP per capita | GDP | Current US$ | WDI |
| Urbanization | URB | Urban Population | WDI |
| Industrial Structure | IS | Index calculated | – |

cross-sectional dependency was analyzed to estimate unbiased long-run estimates. For this purpose, we used two different methods: the Pesaran test [53] and the Breusch and Pagan LM tests [54]. The formulas for the LM and CD tests are given below.

$$LM = T \sum_{i=0}^{N-1} \sum_{j=i+1}^{N-1} \hat{p}_{ij}^2 \quad (6)$$

$$CD = \sqrt{\frac{2T}{N(N-1)}} \sum_{i=0}^{N-1} \sum_{j=i+1}^{N-1} \hat{p}_{ij}^2 \quad (7)$$

where N is the total number of sampled nations, T is the number of years, and $\hat{p}_{ij}$ depicts the cross-sectional correlation between the residuals of two countries, i and j. When cross-sectional dependency was confirmed, then 1st and 2nd generation unit root tests were used to check the integration order of each variable, which indicates the stationarity of the variables at the level or 1st difference. LLC, IPS (1st generation test), and CIPS (2nd generation test) of Pesaran [55] were used. LLC and IPS assume no cross-sectional dependency, which may misguide the selection of an appropriate econometric technique. On the other hand, the CIPS assumes a cross-sectional dependency. After confirming slope heterogeneity, cross-section dependency, and stationarity, we applied Wasterlund [56] to examine the existence of cointegration among the variables. This includes group (Ga, GT) and panel (Pa, Pt) statistics. The rejection of the null hypothesis confirms pre-existing cointegration among the variables.

## Estimation of Short-Run and Long-Run Coefficients

The current study used the cross-sectional augmented autoregressive distributed lag (CS-ARDL) model. This model effectively eliminates the potential impact of disregarding the cross-sectional correlation in the errors. Moreover, this model provides robust estimates in the presence of cross-sectional dependency, endogeneity, and slope heterogeneity [57]. Therefore, the CS-ARDL approach [58] is the best for the current study, and the equation for CS-ARDL is given below.

$$\Delta Y_{it} = \delta_i + \sum_{I=1}^{p} \delta_{iI} \Delta Y_{i,t-1} + \sum_{I=0}^{p} \delta_{iI}^{`} Z_{s.i.t-1} + \sum_{1=0}^{I} \overline{AC}_{i,t-1} + \epsilon_{it}$$

where AC indicates the cross-sectional means and is presented by $\overline{AC_t} = (\Delta Y_t \overline{Z_{s,t}})$, and Z indicates all independent variables.

## Results

Table 3 presents descriptive statistics of the variables used in this study. Normality tests, such as skewness and kurtosis, indicated that most variables deviated from the normal distribution. The JB-test revealed that $lnCO_2$ and lnURB had insignificant results, whereas lnGDP, EPS, and ET had significant outcomes. This implies that $lnCO_2$ and lnURB may follow a normal distribution, and lnGDP, EPS, and ET may be non-normal.

Table 4 shows the results of the slope heterogeneity estimates. The outcomes of both statistics $\hat{\Delta}$ and adj. $\hat{\Delta}$ reveal that the statistically significant estimates are 1%, which implies that the null hypothesis of slope homogeneity is rejected. Therefore, these findings indicate slope heterogeneity.

In the era of globally interconnected nations, it is possible that changes in one nation can affect other nations within a panel. For this purpose, data may depict cross-sectional dependency. To confirm this dependency, the findings of the LM and CD-test in Table 5 indicate that there is cross-sectional dependency among the variables, as shown by the p-value being less than 0.01. This implies that a change in any one nation can influence a change in other nations in the panel.

We used the first-generation (LLC and IPS) and second-generation unit root tests (CIPS) to assess the stationarity of the variables. LLC and IPS confirm that all variables are stationary at their 1st difference under the assumption of no cross-section dependency among the nations in the panel. However, it is strongly evident in the findings that cross-section dependency

Table 3. Descriptive statistics of variables.

| Variables | Mean | Std. Dev. | Min | Max | Skew | Kurt | JB |
|---|---|---|---|---|---|---|---|
| lnCO2 | 5.064 | 1.656 | 0.833 | 9.292 | 0.044 | 3.086 | 0.6215 |
| lnGDP | 9.796 | 1.089 | 5.923 | 11.548 | -1.138 | 4.103 | 263.70* |
| EPS | 1.942 | 1.174 | 0.000 | 4.889 | 0.059 | 1.832 | 56.70* |
| ET | 19.26 | 16.421 | 0.400 | 82.90 | 1.324 | 4.490 | 380.50* |
| lnURB | 16.603 | 1.688 | 12.409 | 20.58 | 0.016 | 2.702 | 3.697 |
| IS | 0.211 | 0.073 | 0.018 | 0.505 | 0.783 | 3.827 | 129.30* |

Note: * significance at 1%; Skew =Skewness, Kurt = Kurtosis, and JB = Jarque Bera Test

is also needed for the 2nd generation test to confirm the stationarity of the variables. Therefore, the results of the CIPS (Table 6) provide strong evidence for all variables regarding stationarity at the 1st difference. This implies that all variables were integrated at the I(1) level after taking the first difference to stabilize the data series.

To analyze the cointegration among the data series, Westerlund's [56] panel cointegration test provides information about whether the variables are cointegrated. The significance of Gt and Ga (Table 7) at 1% rejects the null hypothesis of no cointegration among variables. This implies that the variables have a long-term relationship.

## Regression Outcomes

After satisfying all prerequisite conditions, such as slope heterogeneity and cross-sectional dependency, the current study used CS-ARDL to measure the short- and long-run estimates. This model also effectively tackles the endogeneity problem and provides robust estimates when cross-section dependency exists [59]. The CS-ARDL results are listed in Table 8. The ECM parameter indicates the error correction term, which provides important information about how quickly a dependent variable adjusts to long-run equilibrium after a short-term shock. The ECM value ranges from -1 to 0, and an ECM value close to -1 indicates faster

Table 4. Slope heterogeneity tests.

| Tests | Test scores | p-value |
|---|---|---|
| $\hat{\Delta}$ | 21.582 | 0.00 |
| Adj. Δ | 25.247 | 0.00 |

Note: The dependent variable is $lnCO_2$

Table 5. Cross-section Dependency Test.

| Statistics | $lnCO_2$ | lnGDP | EPS | ET | lnURB | IS |
|---|---|---|---|---|---|---|
| LM-Test | 7006.93* | 14449.55* | 12583.14* | 10209.24* | 15252.35* | 1151.07* |
| CD-Test | 19.61* | 118.94* | 110.35* | 32.16* | 82.86* | 73.56* |

*, significance at 1%. LM-test = Brusche Pagan LM-test, and CD-test = Pesaran CD-test.

Table 6. Unit root test.

| Variables | LLC | | IPS | | CIPS | |
|---|---|---|---|---|---|---|
| | At level | 1st diff | At level | 1st diff | At level | 1st diff |
| $lnCO_2$ | -10.13 | -29.98* | 2.06 | -20.09* | -1.740 | -5.028* |
| lnGDP | -10.25 | -23.25* | 3.85 | -10.62* | -2.283 | -4.001* |
| EPS | -11.25 | -32.37* | 2.19 | -20.35* | -2.675 | -4.994* |
| ET | -7.06 | -29.03* | 4.84 | -18.35* | -1.434 | -4.760* |
| lnURB | -1.82 | -14.99* | -3.46 | -22.60* | -1.541 | -2.277* |
| IS | -2.54 | -44.08* | -1.09* | -33.55* | -4.042* | -6.054* |

Note. * Significance at 1%. LLC= Levin, Lin, and Chu test (2002), IPS= Im, Pesaran and Shin test (2003), CIPS = Pesaran Cross-sectionally augmented IPS test (2007).

Table 7. Panel cointegration tests.

| Statistics | Scores | z-value | Scores | z-value |
|---|---|---|---|---|
| Gt | -2.959* | -2.62 | -3.018* | -3.642 |
| Ga | -5.987 | 1.71 | -5.895 | 1.792 |
| Pt | -13.66* | -3.03 | -14.64* | -3.449 |
| Pa | -6.003 | -1.56 | -4.742 | -1.873 |

Note. * indicates significance level at 1%.

Table 8. Short-run and long-run CS-ARDL estimates.

| Variables | M-1 | | M-2 | |
|---|---|---|---|---|
| | βs | Std. error. | βs | Std. error. |
| Long-run estimates | | | | |
| lnGDP | 0.097** | 0.048 | 0.088** | 0.039 |
| EPS | -0.118* | 0.015 | -0.267* | 0.028 |
| ET | -0.020* | 0.005 | -0.027** | 0.011 |
| ET*EPS | | | -0.312* | 0.003 |
| lnURB | 0.020 | 0.549 | 0.376 | 0.494 |
| IS | -0.018* | 0.004 | -0.038* | 0.002 |
| Short run estimates | | | | |
| ECM(-1) | -0.858* | 0.066 | -0.892* | 0.076 |
| lnGDP | 0.104* | 0.037* | 0.098** | 0.039 |
| EPS | -0.0121 | 0.0112 | -0.199 | 0.218 |
| ET | -0.017* | 0.003* | -0.024** | 0.009 |
| ET*EP | | | -0.204* | 0.006 |
| lnURB | 0.304 | 0.467 | 0.440 | 0.477 |
| IS | 0.002 | 0.036 | 0.024 | 0.042 |

* and ** show significance level at 1% and 5% respectively.

adjustment of the dependent variable to equilibrium after short-term shocks. The significance of the ECM at 1% indicates a need to measure the long-run relations between the variables. Therefore, a negative ECM confirms the existence of long-run equilibrium.

The CS-ARDL model reveals that economic growth has a statistically significant positive impact on $CO_2$ from energy in both the long and short run. The findings indicate that a 1% rise in GDP may cause a 0.097% and 0.104% increase in $CO_2$ emissions in both the long and short run, respectively, in (M-1). Similarly, in (M-2), a 1% rise in GDP causes a 0.088% and 0.098% increase in $CO_2$ emissions in the long and short run, respectively. The findings indicate an insignificant but positive impact of urbanization (lnURB) on $CO_2$ emissions from energy sources. The negative coefficient of IS indicates that transformation in industrial structure has a strong negative impact on $CO_2$ emissions from energy. This implies that improvements in industrial structure will lower $CO_2$ emissions in the long run, while in the short run, IS does not have a strong impact on emissions.

Considering the impact of our important variables, such as ET and EPS, the findings indicate that both ET and EPS have a strong negative impact on $CO_2$ emissions. In (M-1), the one-unit rise in ET causes a 0.02% and 0.017% decrease in $CO_2$ emissions in both the long- and short-run, respectively. Similarly, in (M-2), one unit increase in ET lowered $CO_2$ emissions by 0.027% and 0.024% in both the long- and short-run, respectively. In M-1, a one-point improvement in EPS may cause a 0.118% and 0.012% decline in $CO_2$ emissions from energy in both long-run and short-run analyses of M-1, respectively. Similarly, it decreases $CO_2$ emissions by 0.267% and 0.199% with a one-unit improvement in EPS in both the long- and short-run, respectively. The interaction term of ET and EPS (ET×EPS) also indicates a statistically significant impact on $CO_2$ emissions. Moreover, the negative sign of

ET*EPS indicates that the combined impact of ET and EPS substantially reduces $CO_2$ emissions. This finding implies that environmental policy stringency influences the impact of ET on $CO_2$ emissions. This indicates that stringent environmental policies can boost the role of ET in reducing $CO_2$ emissions. Therefore, these findings suggest that the relationship between ET and $CO_2$ emissions from energy is contingent on stringency in policies, especially environmental policies. Fig. 1 shows a graphical representation of the results.

## Robustness Check

The study used two econometric techniques: AMG and Common Correlated Effects Mean Group (CCEMG), for robustness purposes. The findings of both techniques (Table 9) provide robust evidence for extracting the same conclusion regarding the impact of the variables, as provided by CS-ARDL.

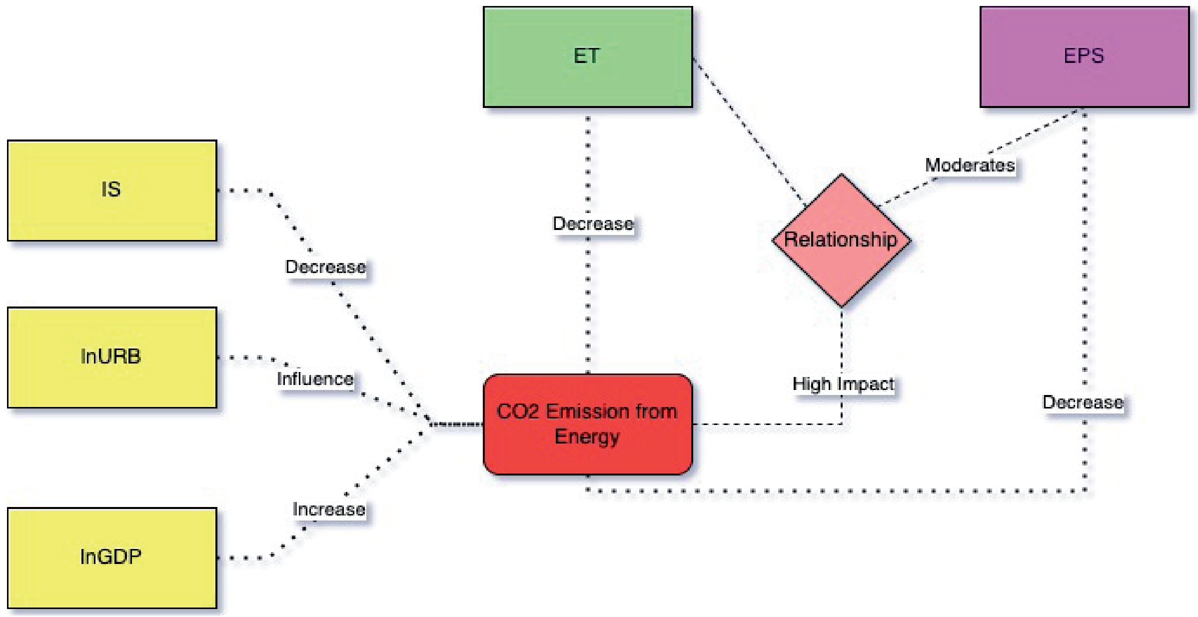


Fig. 1. Graphical representation of CS-ARDL outcomes.

Table 9. Robustness tests.

| Tests/variables | M-1 | | M-2 | |
|---|---|---|---|---|
| AMG | | | | |
| lnGDP | 0.069* | 0.019 | 0.066* | 0.021 |
| EPS | -0.023* | 0.009 | -0.053* | 0.005 |
| ET | -0.019* | 0.002 | -0.024* | 0.007 |
| ET*EPS | | | -0.013* | 0.002 |
| lnURB | 0.722 | 0.661 | 0.677 | 0.538 |
| IS | -0.041* | 0.007 | -0.056* | 0.003 |
| CCEMG | | | | |
| lnGDP | 0.105* | 0.033 | 0.126* | 0.037 |
| EPS | -0.019* | 0.004 | -0.221* | 0.005 |
| ET | -0.015* | 0.002 | -0.012** | 0.006 |
| ET*EPS | | | -0.016* | 0.002 |
| lnURB | 0.614 | 0.459 | 0.391 | 0.480 |
| IS | 0.022 | 0.028 | -0.204* | 0.018 |

* and ** show significance level at 1% and 5% respectively.

## Discussion

Among GHGs, $CO_2$ is primarily responsible for climate change owing to its long-lasting effects on the atmosphere. Moreover, the level of $CO_2$ in the atmosphere is increasing daily, which makes it difficult to achieve global warming of 1.5°or 2° [60]. However, rapid economic growth increases the energy demand, leading to the high use of fossil fuels, which causes $CO_2$ emission in the atmosphere [61]. In order to control $CO_2$ emissions, various initiatives have been initiated worldwide to promote the use of RE. ET is considered a major initiative that can lower $CO_2$ emissions, and it is an inevitable choice to achieve a target of 2° [62]. Therefore, this study aims to analyze the dynamic impact of variables such as ET and EPS, along with GDP, URB, and IS, on $CO_2$ emissions from energy consumption. Moreover, ET is the general choice around the world. When asked how to optimize the ET path, the current study also aimed to analyze whether EPS moderates the favorable impact of ET on $CO_2$ emissions, considering the given levels of GDP, URB, and IS.

The CS-ARDL model revealed the strong negative impact of ET on $CO_2$ emissions. This implies that ET lowers the use of fossil fuels, which are the major contributors to $CO_2$ emissions, and the low consumption of fossil fuels means low emissions of $CO_2$ from energy consumption. Energy transition lowers the dependency on energy from fossil fuels and leads to the adoption of RE sources. Our findings are in line with those of Bouyghrissi et al. [63] and Yuan et al. [64], who reported similar results regarding the impact of ET on $CO_2$ emissions. Saleem et al. [65] described that ET not only reduces $CO_2$ emissions but also generates new employment opportunities in the rapidly expanding sustainable energy industry along with the promotion of energy independence. Moreover, ET in green energy development transforms energy production and consumption, leading to a sustainable future [66]. ET improves energy efficiency and eliminates the use of coal by prioritizing clean energy sources [67].

The findings of this study also indicate that EPS significantly negatively impacts $CO_2$ emissions from energy. This implies how strictly policies are implemented to lower $CO_2$ emissions from energy. The impact of policies on adopting green technologies in each economic sector of a nation can justify this mechanism. Therefore, EPS is a crucial initiative by the government to counter global warming worldwide [68]. Our findings were consistent with those reported by Sezgin et al. [69], Galeotti et al. [70], and Ouyang et al. [71]. Policies allow the selection of an effective and efficient regulatory approach, leading to great compliance outcomes and lower $CO_2$ emissions [72]. Similarly, the effective mechanism of environmentally oriented policies, such as imposing green taxes and stringent policies, generates financial incentives for domestic industries to innovate to lower their emission levels, indicating that EPS effectively lowers emissions over time [73]. Sauvage [74] described that regulation stringency promotes the environmental goods market, enhancing green technologies and reducing low carbon emissions. Sarkodie [75] stated that EPS is necessary to implement environmental rules and regulations to maintain the quality of the environment.

These findings indicate the strong moderating role of EPS in the relationship between ET and $CO_2$ emissions from energy. This implies that the strictness of environment-oriented policies plays a major role in reducing $CO_2$ emissions from energy sources. Wolde-Rufael and Weldemeskel [73] emphasized that the growing intensity of climate change has strengthened the need for more stringent environmental policies and the transition toward RE to address environmental issues. Many nations use various policy tools, such as imposing taxes on energy and transportation, along with different strategies, to encourage the production and consumption of RE [37, 76]. Albulescu et al. [77] stated that the EPS promotes the adoption of cleaner energy technologies that lower $CO_2$ emissions, particularly in the nations with lower emissions. Similarly, Sezgin et al. [69] also described that EPS reduced the use of dirty energy sources, such as fossil fuels, and decreased the emission of $CO_2$ from energy production in the long run. EPS fosters the adoption of green technologies and regulates the energy production process, which lowers the dependency on high-emission energy sources [78]. Moreover, EPS can alter the behavior of producers and consumers toward environmentally friendly production and consumption of energy goods [79, 80]. Yirong [80] and Afshan et al. [39] described the importance of EPS in mitigating $CO_2$ emissions, and they also indicated that the government should complement EPS by adopting green energy strategies to reduce pollution at a better pace. Moreover, environmentally oriented strategies, such as RE and green taxes amid lowering $CO_2$ emissions, are very difficult to achieve without EPS [76].

Economic growth is one of the crucial factors causing $CO_2$ emissions [81]. The current study also reveals a significant positive impact of GDP on $CO_2$ emissions from energy. It is well evidenced in the literature that economic growth demands high energy in its early stages and accelerates the consumption of dirty energy sources, leading to high $CO_2$ emissions from energy [82]. Chebbi and Boujelbene [83] reported that the economic growth of Tunisia primarily drives high $CO_2$ emissions through the inefficient use of energy relative to economic growth. High economic growth has increased the consumption of conventional energy sources, leading to increased $CO_2$ emissions [84]. The findings also reveal a significant long-run reduction effect of IS on $CO_2$ emissions from energy. This implies that the IS can only lower $CO_2$ emissions from energy in the long run. In the long run, IS can promote the use of clean energy and foster the adoption of environmentally oriented technologies to lower $CO_2$ emissions. Gielen and Patel [85] reported that advanced manufacturing technologies can lower $CO_2$ emissions. Moreover, optimizing IS may reduce energy consumption by almost 19%, equal to 1129 million tons of standard coal equivalent [86, 87]. Similarly, IS expansion may cause upgrades in the domestic industry by adopting advanced technologies and lowering energy demand, thus reducing $CO_2$ emissions [88, 89].

## Conclusion

The world is aware of the implications of environmental degradation on the social, economic, and ecological dimensions of sustainability. Therefore, countries are implementing strategies to guarantee financial development without negatively affecting their natural environments. However, increasing carbon productivity while maintaining environmental quality remains an open challenge for both developing and emerging countries. Policymakers use EPS to regulate $CO_2$ emissions and enhance carbon productivity. Moreover, this measure promotes and fosters green growth in economies by regulating them. Attempts have been made to understand the factors influencing carbon emissions, energy consumption, and green growth. However, limited work has been conducted on applying EPS to environmental quality at a global level. Therefore, this study aims to advance the existing knowledge by exploring the moderating role of EPS on the relationship between ET and $CO_2$ emissions from energy by demonstrating the capability of environmental policy and law to foster the complementary aims of sustainable development. Moreover, the present study also aims to examine the effect of energy transition and environmental stringency policy on $CO_2$ emissions from energy.

To achieve the study objectives, the study used the CS-ARDL model on panel data (1995-2020) from 38 countries. Moreover, the study used two econometric techniques, AMG and CCEMG, to check the robustness of the study findings. The findings of both techniques provide robust evidence for extracting the same conclusion regarding the variables' impacts as CS-ARDL provided. The CS-ARDL results revealed that ET and EPS have a strong negative impact on $CO_2$ emission in the short run and in the long run. Additionally, the interaction term of ET and EPS (ET × EPS) also indicates a statistically significant negative impact on $CO_2$ emissions. These findings suggest that the relationship between ET and $CO_2$ emissions from energy is contingent on stringency in policies, especially environmental policies.

Global governments ought to enforce policies and legislation to endorse RE generation. This includes supporting investment in it, offering fiscal incentives to the sector, and nurturing competitive market structures that give policy direction and expectations to the renewed energy business. RE must be encouraged; this will involve providing more funds to ensure the development of new technologies, materials, and equipment for use in the RE sector and to improve RE's efficiency, reliability, and cost. For a higher degree of ES improvement, especially in those countries that experienced a high level of ET, it is necessary to promote the development of RE sources. More efforts should be made on ecological governance using many approaches to control $CO_2$ emissions from various perspectives. Thus, it is prudent for environmental policy to apply flexibility according to the pollution levels. Suppose the level of pollution is comparatively low. In this case, severe regulation can be softened, and detailed attention can be paid to the prevention and treatment of environmental pollution, as well as to raising public awareness of environmental issues and managing the public. On the other hand, timely policy formulation and modification for areas with high pollution should focus on the actual pollution conditions, increase policy standards, and enhance policy enforcement to eliminate pollution problems as efficiently as possible. The policy change should consider a certain country's environment because some countries might have to introduce higher levels of regulations to effectively improve emission cuts.

## Funding

This research was funded by Thuongmai University, Hanoi, Vietnam.

## Conflict of Interest

The authors declare no conflict of interest.

## References

1. IBRAHIM R.L., MOHAMMED A. On energy transition-led sustainable environment in COP26 era: Policy implications from tourism, transportation services, and technological innovations for Gulf countries. Environmental Science and Pollution Research, **30** (6), 14663, **2023**.
2. SHARIF A., KOCAK S., KHAN H.H.A., UZUNER G., TIWARI S. Demystifying the links between green technology innovation, economic growth, and environmental tax in ASEAN-6 countries: The dynamic role of green energy and green investment. Gondwana Research, **115**, 98, **2023**.
3. UDEAGHA M.C., BREITENBACH M.C. Revisiting the nexus between fiscal decentralization and CO2 emissions in South Africa: Fresh policy insights. Financial Innovation, **9** (1), 50, **2023**.
4. IEA. Renewable Energy Outlook. Available online: https://www.iea.org/reports/rene wables-2022/renewable-electricity, **2023**. (accessed at 13 September 2024)
5. IEA. Global Energy Review: $CO_2$ Emissions in 2021. Available online: https://www.iea. org/reports/global-energy-review-co2-emissions-in-2021-2, **2022**. (accessed at 14 September 2024)

6. BEHERA P., HALDAR A., SETHI N. Achieving carbon neutrality target in the emerging economies: role of renewable energy and green technology. Gondwana Research, **121**,16, **2023**.
7. XUE C., SHAHBAZ M., AHMED Z., AHMAD M., SINHA A. Clean energy consumption, economic growth, and environmental sustainability: What is the role of economic policy uncertainty? Renewable Energy, **184**, 899, **2022**.
8. LI C., FIRDOUSI S.F., AFZAL A. China's Jinshan Yinshan sustainability evolutionary game equilibrium research under government and enterprises resource constraint dilemma. Environmental Science and Pollution Research, **29** (27), 41012, **2022**.
9. OZKAN O., EWEADE B.S., USMAN O. Assessing the impact of resource efficiency, renewable energy R&D spending, and green technologies on environmental sustainability in Germany: evidence from a Wavelet Quantile-on-Quantile Regression. Journal of Cleaner Production, **450**, 141992, **2024**.
10. SADIQ M., WEN F. Environmental footprint impacts of nuclear energy consumption: the role of environmental technology and globalization in ten largest ecological footprint countries. Nuclear Engineering and Technology, **54** (10), 3672, **2022**.
11. AVENYO E.K., TREGENNA F. Greening manufacturing: technology intensity and carbon dioxide emissions in developing countries. Applied Energy, **324**, 119726, **2022**.
12. CHISHTI M.Z., AHMAD M., REHMAN A., KHAN M.K. Mitigations pathways towards sustainable development: assessing the influence of fiscal and monetary policies on carbon emissions in BRICS economies. Journal of Cleaner Production, **292**, 126035, **2021**.
13. NAM E., JIN T. Mitigating carbon emissions by energy transition, energy efficiency, and electrification: difference between regulation indicators and empirical data. Journal of Cleaner Production, **300**, 126962, **2021**.
14. ZHOU J.J., ZHAO Y.R., HUANG P., ZHAO X., FENG W., LI Q., XUE D., DOU J., SHI W., WEI W., ZHU G., LIU C. Impacts of ecological restoration projects on the ecosystem carbon storage of inland river basin in arid area, China. Ecological Indicator, **118**, 106803, **2020**.
15. ZEN I.S., AL-AMIN A., DOBERSTEIN B. Mainstreaming climate adaptation and mitigation policy: towards multi-level climate governance in Melaka, Malaysia. Urban Climate, **30**, 100501, **2019**.
16. ZHANG S., YAO L., SUN A., TAY Y. Deep learning-based recommender system: a survey and new perspectives. ACM Computing Survey, **52** (1), 1, **2019**.
17. SHAFIEI S., SALIM R.A. Non-renewable and Renewable Energy Consumption and $CO_2$ Emissions in OECD Countries: A Comparative Analysis. Energy Policy, **66**, 547, **2014.**
18. BILGILI F., KOÇAK E., BULUT Ü. The Dynamic Impact of Renewable Energy Consumption on $CO_2$ Emissions: A Revisited Environmental Kuznets Curve Approach. Renewable and Sustainable Energy Reviews, **54**, 838, **2016**.
19. ERTUGRUL H.M., CETIN M., SEKER F., DOGAN E. The Impact of Trade Openness on Global Carbon Dioxide Emissions: Evidence From the top ten Emitters among Developing Countries. Ecological Indicators, **67**, 543, **2016**.
20. DONG K., DONG X., JIANG Q. How renewable energy consumption lower global CO2 emissions? Evidence from countries with different income levels. The World Economy, **43** (6), 1665, **2020**.
21. AHMAD M., SATROVIC E. Modeling combined role of renewable electricity output, environmental regulations, and coal consumption in ecological sustainability. Ecological Informatics, **75**, 102121, **2023**.
22. SHARIFZADEH M., HIEN R.K.T., Shah N. China's roadmap to low-carbon electricity and water: disentangling greenhouse gas (GHG) emissions from electricity-water nexus via renewable wind and solar power generation, and carbon capture and storage. Applied Energy, **235**, 31, **2019**.
23. SICILIANO G., WALLBOTT L., URBAN F., DANG A.N., LEDERER M. Low-carbon energy, sustainable development, and justice: towards a just energy transition for the society and the environment. Sustainable Development, **29** (6), 1049, **2021**.
24. JOHANSSON B. Security aspects of future renewable energy systems-A short overview. Energy, **61**, 598, **2013**.
25. WANG B., WANG Q., WEI Y.M., LI Z.P. Role of renewable energy in China's energy security and climate change mitigation: an index decomposition analysis. Renew Sust Renewable and Sustainable Energy Reviews, **90**, 187, **2018**.
26. IBRAHIM M.D., ALOLA A.A. Integrated analysis of energy-economic development environmental sustainability nexus: case study of MENA countries. Science of the Total Environment, **737**, 139768, **2020**.
27. GUO L.F., KUANG H.W., NI Z.H. A step towards green economic policy framework: role of renewable energy and climate risk for green economic recovery. Economic Change and Restructuring, **56** (5), 3095, **2023**.
28. KAHIA M., BEN JEBLI M., BELLOUMI M. Analysis of the impact of renewable energy consumption and economic growth on carbon dioxide emissions in 12 MENA countries. Clean Technologies and Environmental Policy, **21**, 871, **2019**.
29. OMRI A., OMRI H., SLIMANI S., BELAID F. Environmental degradation and life satisfaction: do governance and renewable energy matter? Technological Forecasting and Social Change, **175**, 121375, **2022**.
30. OLABI A.G., ABDELKAREEM M.A. Renewable energy and climate change. Renewable and Sustainable Energy Reviews, **158**, 112111, **2022**.
31. YAO H., XU P., WANG Y., CHEN R. Exploring the low-carbon transition pathway of China's construction industry under carbon-neutral target: A socio-technical system transition theory perspective. Journal of Environmental Management, **327**, 116879, **2023**.
32. CARA C., MAROCCO P., NOVO R., KOIVISTO M., SANTARELLI M., MATTIAZZO G. Modeling the long-term evolution of the Italian power sector: The role of renewable resources and energy storage facilities. International Journal of Hydrogen Energy, **59**, 1183, **2024**.
33. BAI L., GUO T., XU W., LIU Y., KUANG M., JIANG L. Effects of digital economy on carbon emission intensity in Chinese cities: A life-cycle theory and the application of non-linear spatial panel smooth transition threshold model. Energy Policy, **183**, 113792, **2023**.
34. YURTKURAN S. The effect of agriculture, renewable energy production, and globalization on $CO_2$ emissions in Turkey: A bootstrap ARDL approach. Renewable Energy, **171**, 1236, **2021**.
35. WANG Y.P., YAN Q., LUO Y.F., ZHANG Q. Carbon abatement of electricity sector with renewable energy

deployment: evidence from China. Renew Energy, **210**, 1, **2023**.

36. SATROVIC E., ADEDOYIN F.F. The role of energy transition and international tourism in mitigating environmental degradation: evidence from SEE countries. Energies, **16** (2), **2023**.
37. ALSAGR N., VAN HEMMEN S. The impact of financial development and geopolitical risk on renewable energy consumption: evidence from emerging markets. Environmental Science and Pollution Research, **28** (20), 25906, **2021**.
38. TURI J.A., ROSAK-SZYROCKA J., MANSOOR M., ASIF H., NAZIR A., BALSALOBRE- LORENTE D. Assessing wind energy projects potential in Pakistan: challenges and way forward. Energies, **15** (23), 9014, **2022**.
39. AFSHAN S., OZTURK I., YAQOOB T. Facilitating renewable energy transition, ecological innovations and stringent environmental policies to improve ecological sustainability: evidence from MM-QR method. Renewable Energy, **196**,151, **2022**.
40. ULUSSEVER T., KILIC DEPREN S., KARTAL M.T., DEPREN O. Estimation performance comparison of machine learning approaches and time series econometric models: evidence from the effect of sector-based energy consumption on $CO_2$ emissions in the USA. Environmental Science and Pollution Research, **30** (18), 52576, **2023**.
41. SCHLINDWEIN L.F., MONTALVO C. Energy citizenship: accounting for the heterogeneity of human behaviors within energy transition. Energy Policy, **180**, 113662, **2023**.
42. DU J., LI F., SUN L. Metal–organic frameworks and their derivatives as electrocatalysts for the oxygen evolution reaction. Chemical Society Reviews, **50** (4), 2663, **2021**.
43. GODAWSKA J., WYROBEK J. The impact of environmental policy stringency on renewable energy production in the Visegrad Group countries. Energies, **14** (19), 6225, **2021**.
44. WANG Z., YEN-KU K., LI Z., AN N.B., ABDUL-SAMAD Z. The transition of renewable energy and ecological sustainability through environmental policy stringency: Estimations from advance panel estimators. Renewable Energy, **188**, 70, **2022**.
45. REN Q., PEI J. Do green financial and non-financial policies achieve the carbon neutrality target? Environmental Science and Pollution Research, **30** (43), 97965, **2023**.
46. FUINHAS J.A., MARQUES A.C., KOENGKAN M. Are Renewable Energy Policies Upsetting Carbon Dioxide Emissions? The Case of Latin America Countries. Environmental Science and Pollution Research, **24** (17), 15044, **2017**.
47. AKELLA A.K., SAINI R.P., SHARMA M.P. Social, Economical and Environmental Impacts of Renewable Energy Systems. Renewable Energy, **34** (2), 390, **2009**.
48. KOENGKAN M. The Decline of Environmental Degradation by Renewable Energy Consumption in the MERCOSUR Countries: An Approach with ARDL Modelling. Environment Systems and Decisions, **38** (3), 415, **2018**.
49. APERGIS N., PAYNE J.E. Renewable Energy, Output, CO2 Emissions, and Fossil Fuel Prices in Central America: Evidence from a Nonlinear Panel Smooth Transition Vector Error Correction Model. Energy Economics, **42**, 226, **2014**.
50. KOENGKAN M., LOSEKANN L.D., FUINHAS J.A., MARQUES A.C. The Effect of Hydroelectricity Consumption on Environmental Degradation – The Case of South America Region. TAS Journal, **2** (2), 46, **2018**.
51. JARQUE C.M., BERA A.K. A test for normality of observations and regression residuals. International Statistical Review/Revue Internationale de Statistique, **55** (2), 163, **1987**.
52. PESARAN M.H., YAMAGATA T. Testing slope homogeneity in large panels. Journal of Econometrics, **142** (1), 50. **2008**.
53. PESARAN M.H. General diagnostic tests for cross section dependence in panels. Cambridge Working Papers. Economics, **1240** (1), 1, **2004**.
54. BREUSCH T.S., PAGAN A.R. The Lagrange multiplier test and its applications to model specification in econometrics. The Review of Economic Studies, **47** (1), 239, **1980**.
55. PESARAN M.H. A simple panel unit root test in the presence of cross-section dependence. Journal of Applied Econometrics, **22** (2), 265, **2007**.
56. WESTERLUND J. Testing for error correction in panel data. Oxford Bulletin of Economics and Statistics, **69** (6), 709, **2007**.
57. ABBAS Q., HONGXING Y., RAMZAN M., FATIMA S. BRICS and the climate challenge: navigating the role of factor productivity and institutional quality in CO2 emissions. Environmental Science and Pollution Research, **31** (3), 4348, **2024**.
58. CHUDIK A., PESARAN M.H. Common correlated effects estimation of heterogeneous dynamic panel data models with weakly exogenous regressors. Journal of Econometrics, **188** (2), 393, **2015**.
59. CHENG Y., YAO X. Carbon intensity reduction assessment of renewable energy technology innovation in China: A panel data model with cross-section dependence and slope heterogeneity. Renewable and Sustainable Energy Reviews, **135**, 110157, **2021**.
60. HAQ S.U., SHAHBAZ P., ABBAS A., ALHAFI ALOTAIBI B., NADEEM N., NAYAK R.K. Looking up and going down: Does sustainable adaptation to climate change ensure dietary diversity and food security among rural communities or vice versa? Frontiers in Sustainable Food Systems, **7**, 1142826, **2023**.
61. VO D.H., VO L.H. International volatility transmission among income, $CO_2$ emission, non-renewable and renewable energy consumption: Which causes which and when? Energy Reports, **8**, 10061, **2022**.
62. DONG F., LI Y., GAO Y., ZHU J., QIN C., ZHANG X. Energy transition and carbon neutrality: Exploring the non-linear impact of renewable energy development on carbon emission efficiency in developed countries. Resources, Conservation and Recycling, **177**, 106002, **2022**.
63. BOUYGHRISSI S., MURSHED M., JINDAL A., BERJAOUI A., MAHMOOD H., KHANNIBA M. The importance of facilitating renewable energy transition for abating $CO_2$ emissions in Morocco. Environmental Science and Pollution Research, **29** (14), 20752, **2022**.
64. YUAN R., MA Q., ZHANG Q., YUAN X., WANG Q., LUO C. Coordinated effects of energy transition on air pollution mitigation and $CO_2$ emission control in China. Science of The Total Environment, **841**, 156482, **2022**.
65. SALEEM H., KHAN M.B., SHABBIR M.S. The role of financial development, energy demand, and technological change in environmental sustainability agenda: evidence from selected Asian countries. Environmental Science and Pollution Research, **27**, 5266, **2020**.

66. XIE X., HOANG T.T., ZHU Q. Green process innovation and financial performance: The role of green social capital and customers' tacit green needs. Journal of Innovation & Knowledge, **7** (1), 100165, **2022**.
67. DE LA PEÑA L., GUO R., CAO X., NI X., ZHANG W. Accelerating the energy transition to achieve carbon neutrality. Resources, Conservation and Recycling, **177**, 105957, **2022**.
68. PINTO G.M.C., PEDROSO B., MORAES J., PILATTI L.A., PICININ C.T. Environmental management practices in industries of Brazil, Russia, India, China and South Africa (BRICS) from 2011 to 2015. Journal of Cleaner Production, **198**, 1251, **2018**.
69. SEZGIN F.H., BAYAR Y., HERTA L., GAVRILETEA M.D. 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, **2021**.
70. GALEOTTI M., SALINI S., VERDOLINI E. Measuring environmental policy stringency: Approaches, validity, and impact on environmental innovation and energy efficiency. Energy Policy, **136**, 111052, **2020**.
71. OUYANG X., SHAO Q., ZHU X., HE Q. XIANG C., WEI G. Environmental regulation, economic growth and air pollution: Panel threshold analysis for OECD countries. Science of the Total Environment, **657**, 234, **2019**.
72. BUSHNELL J.B., HOLLAND S.P., HUGHES J.E., KNITTEL C.R. Strategic policy choice in state-level regulation: the EPA's clean power plan. American Economic Journal: Economic Policy, **9** (2), 57, **2017**.
73. WOLDE-RUFAEL Y., MULAT-WELDEMESKEL E. Do environmental taxes and environmental stringency policies reduce $CO_2$ emissions? Evidence from 7 emerging economies. Environmental Science and Pollution Research, **28** (18), 22392, **2021**.
74. SAUVAGE J. The stringency of environmental regulations and trade in environmental goods, Available online: https://www.oecd-ilibrary.org/content/paper/5jxrjn7xsnmq-en. (accessed at 15 September 2024).
75. SARKODIE S.A. Failure to control economic sectoral inefficiencies through policy stringency disrupts environmental performance. Science of The Total Environment, **772**, 145603, **2021**.
76. TAYLOR C., POLLARD S., ROCKS S., ANGUS A. Selecting policy instruments for better environmental regulation: a critique and future research agenda. Environmental Policy and Governance, **22** (4), 268, **2012**.
77. ALBULESCU C.T., BOATCA-BARABAS M.E., DIACONESCU A. The asymmetric effect of environmental policy stringency on $CO_2$ emissions in OECD countries. Environmental Science and Pollution Research, **29** (18), 27311, **2022**.
78. SOHAG K., MARIEV O., DAVIDSON N. Revising environmental Kuznets curve in Russian regions: role of environmental policy stringency. Environmental Science and Pollution Research, **28** (38), 52873, **2021**.
79. POVITKINA M. The limits of democracy in tackling climate change. Environmental Politics, **27** (3), 411, **2018**.
80. YIRONG Q. Does environmental policy stringency reduce CO2 emissions? Evidence from high-polluted economies. Journal of Cleaner Production, **341**, 130648, **2022**.
81. ACHEAMPONG A.O. Economic growth, $CO_2$ emissions and energy consumption: what causes what and where? Energy Economics, **74**, 677, **2018**.
82. DEVIREN S.A., DEVIREN B. The relationship between carbon dioxide emission and economic growth: Hierarchical structure methods. Physica A: Statistical Mechanics and its Applications, **451**, 429, **2016**.
83. CHEBBI H.E., BOUJELBENE Y. $CO_2$ emissions, energy consumption and economic growth in Tunisia. Available online: https://ageconsearch.umn.edu/record/44016/?v=pdf. (accessed at 15 September 2024).
84. MUJTABA A., JENA P.K., JOSHI D.P.P. Growth and determinants of $CO_2$ emissions: Evidence from selected Asian emerging economies. Environmental Science and Pollution Research, **28**, 39357, **2021**.
85. GIELEN D., NEWMAN J., PATEL M.K. Reducing industrial energy use and $CO_2$ emissions: the role of materials science. MRS Bulletin, **33** (4), 471, **2008**.
86. SHAHZAD M.A., RAZZAQ A., WANG L., ZHOU Y., QIN S. Impact of COVID-19 on dietary diversity and food security in Pakistan: A comprehensive analysis. International Journal of Disaster Risk Reduction, **110**, 104642, **2024**
87. TIAN Y., XIONG S., MA X. Analysis of the potential impacts on China's industrial structure in energy consumption. Sustainability, **9** (12), 2284, **2017**.
88. DONG K. The dynamic optimization model of industrial structure with energy-saving and emission-reducing constraint. Journal of Sustainable Development, **1** (2), 27, **2008**.
89. DONG J., DOU Y., JIANG Q., ZHAO J. How does industrial structure upgrading affect the global greenhouse effect? Evidence from RCEP and non-RCEP countries. Frontiers in Energy Research, **9**, 683166, **2021**.