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**Article**

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## NEXUS BETWEEN ECONOMIC GROWTH AND CO<sub>2</sub> EMISSION WITHIN THE PREVIEW OF INSTITUTIONAL QUALITY: SOME NEW INSIGHTS FROM EUROPE

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### Abstract

The destructive role of institutional quality such as corruption has been considered an important factor for economic growth, particularly in the European Union, where such practices dealt with zero tolerance. Environmental degradation such as massive carbon emissions is stressing the global ecosystem, which has become a solemn issue for environmental policy makers. This research examines the institutional role in controlling corruption within the preview of CO<sub>2</sub> emissions-economic growth nexus for the European Union. The study evaluates the moderating impact of corruption on the relationship between CO<sub>2</sub> emissions and economic growth for the 19 Euro countries over the period 1984-2021, within the context of Auto Regressive Distributed Lag (ARDL) estimation. Empirical results infer that the moderating role of corruption is crucial in measuring the nexus between economic growth and CO<sub>2</sub> emissions due to better institutional quality of the European region. Furthermore, the results confirm that control over corruption plays a special role in the reduction of CO<sub>2</sub> emissions. Furthermore, the study found a significant positive impact of renewable energy production and a negative impact of gross fixed capital formation over controlling CO<sub>2</sub> emission in the long and short run. Furthermore, the Kernel-based Least Squares (KRLS) approach affirms that regressors can bring a variation of 0.984% in the CO<sub>2</sub> emission. The novel finding of the study makes an advance in the current

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literature; we provide real-time examinations of growth and emission for the European Union. The findings are beneficial to environmental economics concerns in designing the environmental policy to seek control over pollution and preserve the natural environment for the European Union. It is also recommended to use renewable wind and solar energy sources to sustain a healthy environment.

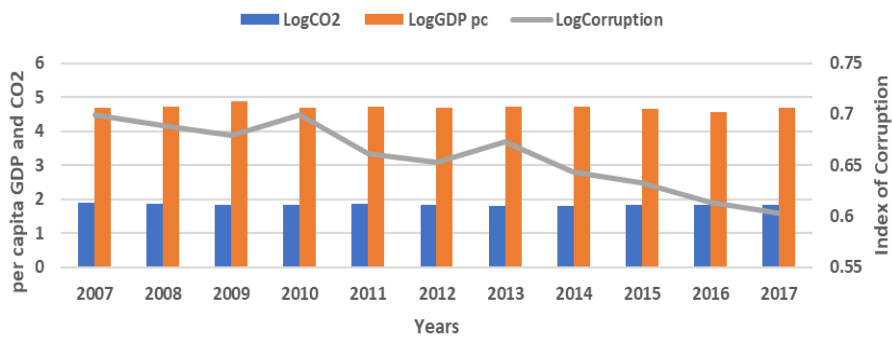
**Keywords:** economic growth, CO<sub>2</sub> emission, corruption, panel data, KRLS, Euro countries

**JEL classification:** O47, O44, D73, C33, N5

**Introduction**

The field of environmental protection has become very important for domestic and international institutions. Policymakers are trying to control the rising population, overconsumption, and rapid technological adaptation. Several strategies, such as the green concept of recycling, low emissions, conversion of conventional energy into renewable energy, and reduction of electricity usage, are used to prevent natural environmental degradation. Earlier research examines the impact of economic growth on environmental issues; the academicians have used several econometric estimations to explore the relationship between the economic indicators. Former researchers have explored the relationship between economic development and environmental precautions using several analytical techniques, including time series and panel data, with a common finding that economic growth is an essential component to overcoming environmental challenges. However, this topic has received a lot of attention since the introduction of the environmental Kuznets curve (EKC) by Grossman and Krueger (1995). The theory of EKC has explained the relationship between indicators of ecological degradation and the development of national income, such as CO<sub>2</sub> and the per capita income of a country. The theory underpins the dominant aspects of modelling pollution concentrations and overall CO<sub>2</sub> emissions.

Some scholars have studied the relationship between CO<sub>2</sub> emissions, economic growth, and corruption by focusing on developing and emerging countries. However, developed economies such as the European Union (EU) are linked with high rates of globalisation, mass production, and experience technological advancement. As a result, these economies are contributing more to natural degradation (Yao et al., 2019). While the EU has good management practices and control on corruption is expected to be low compared to other regions. Figure no. 1 represents the trends in CO<sub>2</sub> emission, economic growth, and corruption in the 19 European economies.



**Figure no. 1. Trends in CO<sub>2</sub> emissions, economic growth, and corruption**

In line with these long-term goals, a research study on the impact of economic growth on CO<sub>2</sub> emission is needed in the context of the EU as these countries are developed in terms of high rates of globalisation, mass production and experience technological advancement, so there are many chances of CO<sub>2</sub> emission because of economic growth. Further, the role of corruption is very important for the EU because corruption can be controlled through good management practices. Therefore, a study is also needed to explore the moderating role of corruption on the relationship between economic growth and CO<sub>2</sub> emission for the EU. Therefore, the current study is initiated to explore how economic growth contributes to CO<sub>2</sub> emission for the EU. Furthermore, this study also explores the moderating role of corruption between the relationship of economic growth and CO<sub>2</sub> emission. We hypothesise on the basis of intuitions and on past literature a significant positive relationship between economic growth and CO<sub>2</sub> emission in the EU. Furthermore, the control of corruption weakens the impact of economic growth on CO<sub>2</sub> emission.

The study contributes to the existing literature in various ways. We have used a larger sample of EU countries and time periods than Wang et al. (2018) to investigate the role of corruption and economic growth in overcoming the challenge of environmental pollution by taking into account renewable energy production, electricity consumption, gross fixed capital formation, and financial development. No specific study has been conducted to examine the impact of income growth on the protection of the natural environment in the EU. The European countries were chosen because the region consumes a large share of oil and gas for both industrial and household purposes, particularly during the winter. Furthermore, the region has a progressive institutional framework to regulate carbon emissions, such as a carbon tax, which justifies the peculiar region's selection. The moderating role of corruption encourages policymakers to approach new strategies to implement climate change legislation on corruption and income levels in order to address environmental challenges. We used the ARDL estimation approach introduced by Sek et al. (2022) with the addition of the pooled mean group (PMG), mean group (MG), and dynamic fixed effect (DFE) estimators to estimate the real-time impact of such important indicators. The Hausman test is used to determine the best estimation technique.

The finding of this study is very important for the EU in several ways, as the destructive role of institutional quality, such as corruption, has been identified as an important factor for economic growth, particularly in the EU, where such practices are treated with zero tolerance. Moreover, environmental degradation, such as massive carbon emissions, is putting a strain on the global ecosystem, which has become a sore point for environmental policymakers. Similarly, environmental pollution is caused by a variety of factors, and this study investigates the institutional role in controlling corruption within the context of the EU's CO<sub>2</sub> emissions-economic growth nexus. The findings are useful for environmental economists in developing environmental policies to control pollution and preserve the natural environment for the EU. Wind and solar renewable energy sources are also suggested to be used to maintain a healthy environment.

The remainder of the study is organised as follows: section 1 covers the review of literature, section 2 explains the data and methodological approach. Section 3 describes the estimations and discussion, and finally, the last section concludes the study with policy implications.

## 1. Literature review

Theoretically, institutions should encourage and strengthen the protection of property rights in order to promote voluntary exchange and assist authorities in formulating and implementing policies for sustainable development (Bhattacharya et al., 2017). Therefore, the efficacy of environmental and renewable energy regulations is contingent upon the effectiveness of institutions; without efficient institutions, environmental and renewable energy policies will not produce the desired results. In addition, Omri (2014) argues that institutions influence both the rate of economic growth and the implementation efficiency of energy policies. Furthermore, stronger institutions lead to more rigorous environmentally friendly and energy policies (Cadoret and Padovano, 2016).

### 1.1. Corruption and CO<sub>2</sub> emissions

Historically, corruption is defined as an evil in the ecological system, and theoretically explanation about the environmental negative impact of corruption is uncertain. Among two strands of literature, one focuses on the rules and regulation and argues that corruption substantially affects environmental regulation because corruption shaped the policies in the corrupt societies (Fredriksson et al., 2004). The second strand explains that corruption hinders law implication, consequently permitting emitters to avoid obligation of pollution or inspiring the overexploitation of resources (Schmiedeknecht, 2013).

Sinha et al. (2019) scrutinise the impact of corruption in the public sector on CO<sub>2</sub> emission in NEXT-11 and BRICS countries over 1990-2017. They confirm that corruption enhances the environmental degradation by dampening the positive impact of renewable energy consumption on CO<sub>2</sub> emissions. Using the provincial data of China from 2005 to 2015 and system of GMM, Pei et al. (2021) analysed the impact of corruption and energy efficiency on industrial CO<sub>2</sub> emission. The findings outline that corruption enhances the CO<sub>2</sub> emission, while energy efficiency helps to mitigate. Haseeb and Azam (2021) evaluate the impact of corruption, democracy, tourism on CO<sub>2</sub> emission. Using data from 1995 to 2015 and the FMOLS estimation technique, the findings support the view that endemic corruption and tourism are key contributors to CO<sub>2</sub> emissions. Moreover, they explain that the impact of CO<sub>2</sub> emission is higher in low-income countries than in high-income countries. Wang et al. (2018) explore the moderating role of corruption on the relationship between CO<sub>2</sub> emission and economic growth over the data span 1996-2015. The findings indicate that the overall impact of corruption is more important, and the control of corruption reduces CO<sub>2</sub> emission. In case of corruption impact on environmental quality, the panel set of 61 developed and developing countries from 2003 to 2016 is considered. CO<sub>2</sub> emission is no longer influenced by corruption in developed countries, while CO<sub>2</sub> emission decreases with the increase in corruption score in the developing countries (Akhbari and Nejati, 2019). Further, the impact of corruption on CO<sub>2</sub> emission is examined in African countries by using the GMM estimation approach. Empirical evidence indicates that corruption impact is negative in lower emission countries, however, an insignificant impact is found in high emission countries; on CO<sub>2</sub> emission (Habib et al., 2020). Using the panel of 64 developing counties, Masron and Subramaniam (2018) explore the direct and indirect impact of corruption on environmental degradation. The GMM estimator confirms that corruption exhibits a positive impact on pollution and further elaborates that pollution levels tend to be higher in the higher corrupt countries.

## 1.2. Economic growth and CO<sub>2</sub> emission

In the early 1960s, Grossman and Krueger (1995) scrutinised the association between income per capita and environmental degradation which are evident of the inverted U-shape curve called environmental Kuznets curve (EKC). Since then, many studies explored the EKC but the association between environmental degradation and income per capita has been on the top. For example, long run association between financial development, energy consumption and economic growth on CO<sub>2</sub> emission in Turkey from 1965 to 2016 is analysed by Doğanlar et al. (2021). This study applied the residual augmented least squares-Engle and Granger and dynamic ordinary least squares econometric approaches. The results revealed that economic growth impacts statistically significant and negatively to CO<sub>2</sub> emission while other positively contribute. Asymmetric relationship between economic growth, FDI, energy use, and CO<sub>2</sub> emission in India is estimated using the non-linear ARDL estimation technique. The findings reveal that when economic growth increases, CO<sub>2</sub> emission decreases and further evidence of an inverted U-shaped relationship between economic growth and CO<sub>2</sub> emission (Mujtaba and Jena, 2021). Likewise, non-linear relationship between economic growth drivers on CO<sub>2</sub> emission is scrutinised in India; the results claim that prevailing economic growth framework in India is environmental unsustainable because of dependency on other factors such as crude oil, fossil fuel (Shahbaz et al., 2021). A panel data study focused on the 50 African countries from 1980 to 2018 to find out the empirically long run relationship between economic growth on CO<sub>2</sub> emission along with other influencers (Mujtaba and Jena, 2021). They found the negative impact of economic growth on CO<sub>2</sub> emissions in African countries, but the mixed level across regions and the income level.

A recent study by You et al. (2022) explores the association between economic growth, economic complexity, and CO<sub>2</sub> emission on the panel of 95 countries (low-income countries, middle-income countries, high-income countries) from 1996 to 2015. A latest panel Granger causality approach confirm the bi-directional causality among the selected variables. Further, they suggest that both developed and developing countries should make a reasonable CO<sub>2</sub> emission plan and thus maintain the balance between economic complexity and CO<sub>2</sub> emission. Likewise, Chen et al. (2022) analyse the relationship between economic growth, urbanisation, energy consumption, population growth and economic growth during 1990-2019 in Brazil, Russia, India, South Africa (BRICS). Using the augmented mean group and common correlated mean group estimation approaches, the results reveal that economic growth is the positive factor for CO<sub>2</sub> emissions, while energy consumption worsens environmental quality. Rahaman et al. (2022) scrutinised the impact of FDI, tourism, electricity consumption, and economic development on CO<sub>2</sub> emission from 1990 to 2019 in Bangladesh. The consequences indicate that FDI, electricity consumption and economic development statistically and significantly impact the CO<sub>2</sub> emission. Moreover, the impact of globalisation, energy consumption, and economic growth on environmental quality is scrutinised by using FMOLS in South Asian countries. The study discovers that economic growth deteriorates the environmental quality in the selected region. In light of the discussion, there is a significant positive relationship between economic growth and increased economic growth. The applied estimation approach concludes that economic growth is conducive to environmental degradation.

### **1.3. Renewable energy production and CO<sub>2</sub> emissions**

Renewable energy sources are the least costly sources in escalating electricity access, reducing air pollution, and cutting carbon emissions worldwide. Using the ARDL estimation approach, Chen et al. (2019) find the negative impact on CO<sub>2</sub> emissions in China and further confirm the bidirectional causality from CO<sub>2</sub> emission to renewable energy production. Another study based on Brazil, India, China outlined that the overall impact is significant in combating environmental degradation. Similarly, Olah et al. (2021) depict the negative influence on CO<sub>2</sub> in the context of India. Sinha and Shahbaz (2018) confirm that renewable energy sources play an important role in mitigate the CO<sub>2</sub> emission in 85 developed and developing countries. In the case of Italy, Cerdeira Bento and Moutinho (2016) think that per capita renewable energy production reduces the CO<sub>2</sub> emission level both in the short run and long run. A recent research study by Mostafaeipour et al. (2022) report a significant reduction in CO<sub>2</sub> emission is possible through fossil fuel subsidy eliminating. Moreover, the authors claim that this reduction can be achieved from 7% to 41% by doing so accordingly. Inglesi-Lotz and Dogan (2018) claim a similar role in reducing CO<sub>2</sub> in 10 big electricity generator countries from SSA. On the contrary, Yurtkuran (2021) reports the positive impact of renewable energy production on CO<sub>2</sub> emission for Turkey.

### **1.4. Electricity consumption and CO<sub>2</sub> emissions**

A research study in Bangladesh evaluates the relationship between globalisation, FDI, trade, urbanisation, energy consumption, innovation, and institution quality on CO<sub>2</sub> emission from 1972 to 2016 (Islam et al., 2021). Similarly, in the new industrialised countries from 1979 to 2017 the impact of energy use, export, economic growth, and human capital on CO<sub>2</sub> emissions is scrutinised (Rahman et al., 2022). The panel estimation techniques such as DOLS, FOLS and PMG are applied to conclude the main results. The findings indicate that energy use and export dampen the environmental quality. The study applied a novel dynamic ARDL approach and found that energy consumption and urbanisation positively contribute to CO<sub>2</sub> emission and thus upsurge environmental degradation both in long and short run. Energy consumption with a positive shock positively impacts CO<sub>2</sub> emissions in India during 1986-2014 (Mujtaba and Jena, 2021). In China, Jiang et al. (2021) investigated the effect of energy production and consumption on CO<sub>2</sub>. Their findings depict that energy production and consumption significantly contributed to the environmental pollution in the long run and short run. Likewise, using the novel dynamic ARDL approach confirms that economic growth and energy use statistically and positively impact CO<sub>2</sub> emissions (Abbasi and Adedoyin, 2021). A time series study developed by Abbas et al. (2021) in Pakistan, from 1970 to 2018 validated the insignificant impact of traditional energy on CO<sub>2</sub> emissions.

### **1.5. Gross fixed capital formation and CO<sub>2</sub> emissions**

The investment in the capital goods is authentic cornerstone to gear the economic structure linked with the resource use and environmental impacts. Nevertheless, its poisonous impacts on the environment are equally incontrovertible. With regard to this stark reality, there is a plethora of empirical studies on the relationship between gross capital formation and CO<sub>2</sub> emission. The panel study based on the one belt one road from 1995 to 2014 evaluated the impact of GDP, gross capital formation, renewable and renewable energy on CO<sub>2</sub> emission

(Abbas et al., 2021). The ARDL estimation approach indicates the enhancement in GDP and thus environmental quality can be further improved. The research study developed by Adebayo and Beton Kalmaz (2021) in Egypt from 1971 to 2014 on the determinants of CO<sub>2</sub> emission does not outline a significant relationship between gross capital formation and CO<sub>2</sub> emission. An annual time series study developed by Rahman and Ahmad (2019) aims to evaluate the association between coal, oil consumption, gross capital formation, and CO<sub>2</sub> emission in the case of Pakistan during 1980-2016. Their results affirm the asymmetric impact of changes in gross capital formation shocks on CO<sub>2</sub> emissions both in the long and short run. Similarly, Mujtaba et al. (2022) scrutinise the linear and non-linear impact of capital formation, economic growth, renewable, non-renewable energy consumption on CO<sub>2</sub> emission in 17 OECD countries during 1970-2016. The results affirm that economic growth and capital formation dampen the environmental quality.

### 1.6. Financial development and CO<sub>2</sub> emissions

Financial development is not only the crucial driver of economic growth but also of CO<sub>2</sub> emission in the environment. The Generalised Model of Moments (GMM) estimation approach is used to evaluate the direct and indirect impact of financial development on environmental pollution in 88 developing countries (Khan and Ozturk, 2021). Besides, using the long historical data on G7 countries, Shahbaz et al. (2021) analyse the financial development impact on CO<sub>2</sub> emissions for each country. Time-varying and boost strapping rolling window indicate that financial development on CO<sub>2</sub> emission is M-shaped in the US, Japan and Canada, whereas N-shaped in France, Italy, and UK, and inverted M shape in Germany. A spatial impact of financial development on CO<sub>2</sub> emission is scrutinised on the set of 97 countries from 2000 to 2014 (Lv and Li, 2021). The findings suggest that financial development mitigates CO<sub>2</sub> emission and thus could enhance the environmental quality. Using data from 2000 to 2014 on five different financial development indicators, it was concluded that financial development plays a key role in reducing pollution level in the selected countries. A time series study based on Turkey finds the positive contribution of financial development to CO<sub>2</sub> emission (Doğanlar et al., 2021). A recent panel study based on the 31 Asia Pacific Countries from 2000 to 2018 concluded that six financial growth metrics are relevant and enhance CO<sub>2</sub> emission (Khezri et al., 2021). With the aim to explore the impact of urbanisation, renewable energy consumption, economic growth, financial development, and agriculture on CO<sub>2</sub> emissions, Anwar et al. (2022) focused on 15 Asian countries for the period of 1990-2014. Their findings suggest that financial development along with other factors except the agriculture tends to reduce CO<sub>2</sub> emission. Petrović and Lobanov (2022) selected 24 counties for the investigation of financial development on CO<sub>2</sub> emission from 1970 to 2014. Their primary aim was to conclude whether financial development enhance or dampen the CO<sub>2</sub> emission. So, advance estimation approaches support the positive long-term impact of financial development on CO<sub>2</sub> emission. An investigation on the impact of financial development in MINT (Mexico, Indonesia, Nigeria, Turkey) countries from 1969 to 2019 from the rolling window indicates the feedback casual association between financial development and CO<sub>2</sub> emission.

Considering all the previously outlined information, the theoretical framework specific to the present study is illustrated in Figure no. 2



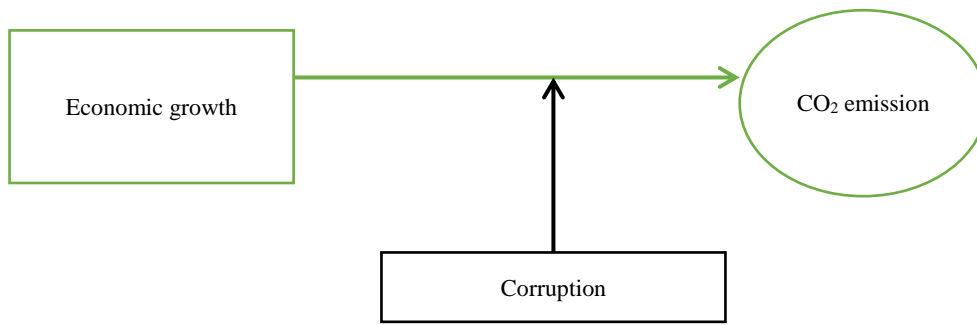


Figure no. 2. Theoretical framework and model of the study

2. Data and methodology

This study aims to assess the moderating role of corruption in the economic growth-CO<sub>2</sub> emissions nexus with other control variables. Economic growth is measured using proxy GDP per capita, and CO<sub>2</sub> emission is measured in metric tons per capita. Renewable energy is the production of total renewable energy sources. Gross fixed capita formation is the land improvement, plant, machinery and equipment purchase. Whereas financial developments entail the creation and growth of institutions and markets that facilitate the growth and investment process. Corruption data is taken from the international country risk guide (ICRG), and percentage rank 0 (highest) to 10 (lowest) is a measure of levels of corruption while fixed capital and FDI data are taken from the World Bank. Finally, financial development data are taken from the International Monetary Fund (IMF). Table no. 1 shows the summary and units of measurement for all variables.

Table no. 1. Variables and sources

Variables	Acronym	Units	Sources
CO <sub>2</sub> emissions	CO <sub>2</sub>	Per capita	US Energy Information Administration
Gross domestic per capita	GDPpc	US dollar	World Bank
Corruption	Cor	0=High, low10	International Country Risk Guide
Renewable energy production	REP	Kilowatt hour	US Energy Information Administration
Gross fixed capital formation	GFCF	% of GDP	World Bank
Electricity consumption	EC	Quad Btu	US Energy Information Administration
Financial development	FD	% of GDP	International Monetary Fund

2.1. Empirical model

The current study applied the ARDL model with the pooled mean group (PMG), mean group (MG), and dynamic fixed effect (DFE) estimators. Hausman test is used to select the appropriate estimation technique. The functional form of the established model is presented in equation (1) by following (Sek et al., 2022).

$$y_{it} = \sum_{j=1}^p \lambda_{ij} y_{it-j} + \sum_{j=0}^q \delta_{ij} x_{it-j} + \varepsilon_{it} \quad (1)$$

In the equation (1),  $i=1,2,\dots,N$  denotes to countries= $1,2,\dots,T$  presented the time period,  $p$  is the lag number of dependent variables,  $q$  is the lag number of independent variables. The  $y_{it-j}$  and  $x_{it-j}$  are represented in vector  $k \times 1$ .  $\delta_{ij}$  displayed in  $k \times 1$  co-efficient vector  $\lambda_{ij}$  vector of scaler. Below equation (2) represents the error correction form.

$$\Delta y_{it} = \phi_i y_{it} + \hat{\beta}_i y_{it} + \sum_{j=1}^{p-1} \lambda_{ij}^* \Delta y_{it-j} + \sum_{j=0}^{q-1} \delta_{ij}^* \Delta x_{it-j} + \varepsilon_{it} \quad (2)$$

In Equation (2),

$$\phi_i = 1 - \sum_{j=1}^p \lambda_{ij}; \beta_i = \sum_{j=0}^q \delta_{ij} = \sum_{m=j+1}^p \lambda_{im}, j = 1, 2, \dots, p-1; \delta_{ij}^* = \sum_{m=j+1}^q \delta_{im}, j = 1, 2, \dots, q-1.$$

The equation can be written as:

$$\Delta y_{it} = \phi_i (y_{it-1} - \hat{\theta}_i y_{it} + \sum_{j=1}^{p-1} \lambda_{ij}^* \Delta y_{it-j} + \sum_{j=0}^{q-1} \delta_{ij}^* \Delta x_{it-j} + \varepsilon_{it} \quad (3)$$

$\hat{\theta}_i = \hat{\beta}_i / \phi_i$  presents the association between  $y_{it}$  and  $x_{it}$ , whereas  $\delta_{ij}^*$  and  $\lambda_{ij}^*$  describe the short term effect of  $y_{it}$  and  $x_{it}$ . The error correction coefficient  $\phi_i$  is used to measure the speed of adjustment on  $y_{it}$  due to changes in  $x_{it}$  which must be negative, indicating convergence to the long-run equilibrium. If  $\phi_i$  is positive, it is not convergence to long-run equilibrium, and there is no long-run association in the model.

## 2.2. Estimation process

The use of panel data in research study analysis has some benefits and drawbacks. One of the data set's critical weaknesses is its problem with heterogeneity and spatial dependence. Regardless of this, panel data gives more liberty and sample variation than time-series data (Ertugrul et al., 2016; Appiah et al., 2019). However, with the introduction of modern statistical methods, the panel data eliminate these pitfalls (Pesaran, 2004; Pesaran, 2007b). For this reason, the main steps of our research are to resolve such hitches that are suitable for the quantitative panel models in the estimations. The cross-sectional dependence test provides a measuring stick for the set of other econometric approaches to be used in the analysis, such as the root unit panel test and the co-integrating test. Consequently, conclusions could be skewed if the issue of cross-sectional dependence is ignored (Paramati et al., 2017). So, we applied the Psarian (2004) cross-sectional dependency (CD) measures. As cross-sectional dependency exists in the data, the first-generation unit root test cannot be carried out. Therefore, we will use the cross-sectional augmented Dickey-Fuller (CADF) and cross-sectional IPS (CIPS) unit root tests of the second generation suggested by (Pesaran, 2007b). When the data are probed for the unit root test, this test has power over the cross-sectional dependency matter. The suitable unit root test selection increases the results' reliability (Paramati et al., 2017). The null hypothesis suggests that the variable is not stationary. The second-generation panel co-integration test between the variables is needed after running the panel data's second-generation unit root. The following equation is used to compute the CADF statistic:

$$\Delta Y_{it} = \alpha_i + b_i Y_{i,t-1} + c_i Y_{t-1}^- + c_i \Delta Y_t^- + \omega_{it} \quad (4)$$

Where  $\Delta$  shows the difference operator,  $Y$  is the analysed variable, and  $\omega$  presents the error terms. Based on the CADF statistic, PESARAN (2007A) established the CIPS statistic, which can be stated as follows:

$$CIPS = -\frac{1}{N} \sum_{i=1}^N CADF_i \tag{5}$$

In the presence of cross-section dependency and heterogeneity, the traditional econometric techniques such as the generalised method of moment (GMM), random effect, and fixed effect are not suitable to exercise (Ren et al., 2014). Pesaran and Smith (1995) state that the MG estimation techniques deal with the heterogeneity in all coefficients of the model. The PMG and DFE are almost similar; however, the big difference is that DFE estimation technique bound the coefficient of the speed of adjustment and the short-term coefficient to be equal across all panels. Besides, the DFE estimator enforces the homogeneity of short- and long-run parameters. Alike to the PMG and MG estimators, all coefficients from the DFE estimate are correctly signed. In summary, MG considers the average value of approximations across countries with less limitations, whereas DFE executes the maximum boundaries and seems to overestimate the slopes. PMG has the middle constraint, with the only restriction being on the long-run slope, which is the same for all countries. No restriction is imposed on the short-run estimates. Hausman estimation method was used to determine the relationship between the model of MG, PMG and DFE. It is used to choose which of the two models fits: in this analysis.

**3. Empirical results**

Table no. 2 displays descriptive statistics for 19-EURO countries, with all values converted to natural log except for electricity consumption (EC) and financial development (FD). The mean value of CO<sub>2</sub> emissions (LCO<sub>2</sub>) is 4.19, economic growth (Lgdppc) is 9.78, corruption (LCor) is 1.40, renewable energy production (LREP) is 1.73, electricity consumption (EC) is 2.39, gross fixed capital formation (LGFCF) is 21.76, and financial development (FD) is .547. Gross fixed capital formation has the highest variation in terms of standard deviation, while financial development has the lowest variation. Except for energy consumption and gross fixed capital formation, the data are skewed. Excess kurtosis is detrimental to corruption and financial development while positive for all other variables.

**Table no. 2. Descriptive statistics**

Variables	Mean	Standard Deviation	Kurtosis	Skewness	Minimum	Maximum
<b>LCO<sub>2</sub></b>	4.193	1.300	0.104	-0.626	0.113	6.165
<b>LGDPpc</b>	9.784	1.021	0.796	-0.926	5.299	11.818
<b>LCor</b>	1.406	0.308	-0.392	-0.699	0.693	1.792
<b>LREP</b>	1.731	2.199	0.360	-0.827	-6.908	4.806
<b>EC</b>	2.394	2.641	2.319	1.701	0.015	11.465
<b>LGFCF</b>	21.763	3.695	9.739	0.919	4.452	53.591
<b>FD</b>	0.547	0.188	-0.587	-0.349	0.000	0.902

Table no. 3 depicts the relationship between independent variables. In absolute terms, the lowest correlation exists between corruption and renewable energy production (0.021), while the highest correlation is observed between economic growth and financial development

(0.76). The absence of multicollinearity is indicated by a correlation between independent variables that does not exceed 0.80.

**Table no. 3. Correlation matrix**

	LGDPpc	LCor	LREP	EC	LGFCF	FD
LGDPpc	1					
LCor	0.344	1				
LREP	0.211	-0.021	1			
EC	0.087	-0.076	0.554	1		
LGFCF	0.084	0.120	0.085	-0.040	1	
FD	0.762	0.186	0.225	0.227	-0.068	1

Table no. 4 reports the results of cross-sectional dependence by applying four tests. The Breusch-Pagan LM, Pesaran scaled LM, Bias-corrected scaled LM and Pesaran CD are significant for all of the variables at 1% level of significance, so rejected the null hypothesis of no cross-section dependence. The presence of cross-sectional dependence implies to use second generation unit root test to check the stationarity of each variable.

**Table no. 4. Cross-Sectional Dependence test**

Series	Breusch-Pagan LM	Pesaran scaled LM	Bias-corrected scaled LM	Pesaran CD
LCO2	2427.51***	122.02***	121.76***	13.31***
LGDPpc	5718.64***	299.98***	299.73***	75.32***
LCor	1596.65***	77.09***	76.83***	27.82***
LREP	3782.08***	195.26***	195.01***	54.35***
EC	3489.77***	179.46***	179.20***	18.47***
LGFCF	903.94***	39.63***	39.38***	13.86***
FD	3868.62***	199.94***	199.69***	58.99***

Notes: \*\*\*, \*\*, \* show the significance level at 1%, 5% and 10%, respectively

Table no. 5 provides results of second-generation unit root test by applying cross-section Im-Pesaran (CIPS) and Cross-section Augmented Dickey-Fuller (CADF). The result points out that the integration order is mixed, i.e., I (0) and I (1). This level of integration in penal data is preferred condition for applying panel autoregressive distributed lag (Panel-ARDL) model in the presence of cointegration.

**Table no. 5. Second Generation Unit Root Test**

Variables	CIPS			CADF	
	I(0)	I(1)		I(0)	I(1)
LCO2	-2.192**	-5.693***		-1.625	-3.012***
LGDPpc	-1.927	-4.760***		-1.953	-3.041***
LCor	-1.932	-4.976***		-2.093*	-3.662***
LREP	-3.190***	-----		-2.108*	-3.513***
EC	-1.866	-4.962***		-1.679	-3.413***
LGFCF	-1.832	-4.792***		-1.232	-3.315***
FD	-3.493***	-----		-2.546***	-----

Notes: \*\*\*, \*\*, \* show the significance level at 1%, 5% and 10%, respectively

Table no. 6 provides the results for panel cointegration tests using Kao Residual and Johansen Fisher panel cointegration tests. The t-statistics of the Kao residual test is significant at 1% level, whereas the trace test and the Max-Eigen test of the Johansen Fisher panel cointegration test are significant for most of the cointegrating equations. It indicates the presence of cointegration among variables. Therefore, on the basis of second-generation unit root test at mixed order of integration and presence of cointegration, the panel ARDL model is applicable.

**Table no. 6. Panel Cointegration Test**

Kao Residual Cointegration Test			Johansen Fisher Panel Cointegration Test				
ADF	T-Statistic	Prob.	Hypothesised No. of CE(s)	Fisher Stat (Trace test)	Prob.	Fisher Stat (Max-Eigen test)	Prob.
	-3.871	000	None	755.9	000	521.9	0.000
			At most 1	730.7	000	328.3	0.000
			At most 2	404	000	160	0.000
			At most 3	256.3	000	101.7	0.000
			At most 4	166.2	000	71.41	0.001
			At most 5	112.7	000	55.6	0.033
			At most 6	78.44	000	47.07	0.149
			At most 7	59.92	0.013	55.9	0.031
			At most 8	47.73	0.134	47.73	0.134

Table no. 7 shows the Hausman test results for selecting a model from three variants of the panel ARDL model; mean group model (MG), pool mean group model (PMG), and dynamic fixed effect model (DFE). The null hypothesis between PMG and MG is that PMG is more efficient, and the null hypothesis is rejected if the coefficient of the chi-square is significant. As a result, the MG model was chosen over the PMG model because the coefficient of chi-square value for the Hausman test is significant at the 1% level. Similarly, the null hypothesis between MG and DFE is that DFE is more efficient, so an insignificant p.value rejected the null hypothesis, indicating that DFE is a better model than MG. Finally, the null hypothesis is that PMG is more efficient than DFE, so significant p.value employ that DFE is a better model than PMG. The DEF model will be used in this study.

**Table no. 7. Hausman (1978) specification test**

	PMG Vs MG	MG Vs DFE	DFE Vs PMG
	Coef.	Coef.	Coef.
<b>Chi-square test value</b>	33.854	1.771	372.894
<b>P-value</b>	0.000	0.987	0.000

Table no. 8 shows the estimated results for the panel ARDL dynamic fixed-effects regression (DFE) model. More importantly, this study finds no moderating role of corruption in the economic growth-CO<sub>2</sub> emissions nexus because of specific controlling strategies on corruption in the Euro countries. The results are opponent with the findings of Wang et al. (2018). Their findings state that moderating role of corruption is noticed when the institutional performance is poor. Hence, the environmental quality and controlling of corruption along with the economic growth have been main motive of the Euro countries. It

is also obvious from the graphically presentation of these variables, that corruption is significantly declining, while the economic growth is progressing with the improve of environmental quality.

Renewable energy production (REP) is significant at the 1% level and indicates that with a 1% increase in the renewable energy production, the CO<sub>2</sub> emission will increase by 0.365%. These results are aligned with the ones of Yurtkuran (2021) and opposite to the ones of Mostafaiepour et al. (2022). They discover that producing energy from the particularly from those resources that contribute to CO<sub>2</sub> emissions impure the environmental quality. In the short-run, economic growth (Lgdppc), renewable energy production (Lrep), and electricity consumption (EC) are all significant at 1%. However, REP has a negative relationship with CO<sub>2</sub> emissions. The coefficient of error correction term (Ect) is negative and significant, representing the adjustment speed of long-run equilibrium relationship.

**Table no. 8. Dynamic Fixed Effects Regression: Estimated Error Correction Form**

	Variables	Coef.	Std.Err.	P.value
<b>Long Run</b>	LGDPpc	0.232	0.195	0.235
	LCor	0.373	1.232	0.762
	LREP	0.365	0.082	0.000
	EC	-0.48	0.361	0.184
	LGFCF	-0.200	0.036	0.000
	FD	-0.003	0.008	0.712
	LCor*LGDPpc	-0.036	0.131	0.784
<b>Short Run</b>	Ect	-0.074	0.011	0.000
	LGDPpc	0.048	0.018	0.007
	LCor	0.003	0.023	0.882
	LREP	0.241	0.02	0.000
	EC	0.092	0.05	0.064
	LGFCF	-0.052	0.005	0.000
	FD	0.001	0.001	0.302
	Cons	0.126	0.138	0.36

Table no. 9 depicts the pointwise derivates results which attained by applying machine learning approach called KRLS. Results indicate that all variables are significantly causing the economic growth, except the gross fixed capital formation. The R<sub>2</sub> value of that model is significant with a predictive power of 0.984%. It indicates that regressors can bring variation in the CO<sub>2</sub> emission at 0.984%. An evaluation of heterogeneous marginal effects using derivatives of regressors is conveyed 25<sup>th</sup>, 50<sup>th</sup>, and 75<sup>th</sup> percentiles. It can be observed that mean pointwise marginal effects of corruption, GDP, renewable energy production, electricity consumption, gross fixed capital formation, and financial development are -0.038%, -0.092%, 0.08%, 0.608%, -0.006 and 0.125%. However, it can be observed that mean pointwise 25% effects of corruption, GDP, renewable energy production, electricity consumption, gross fixed capital formation, FDI and financial development are -0.244%, -0.233%, 0.01%, 0.608%, 0.305%, -0.19% and -0.06%. Similarly, mean pointwise 50% effects of corruption, GDP, renewable energy production, electricity consumption, gross fixed capital formation, FDI and financial development are -0.078%, -0.069%, 0.08%, 0.643%, 0.02%, and 0.86%. Finally, mean pointwise 75% effects of corruption, GDP, renewable energy production, electricity consumption, gross fixed capital formation and financial development are 0.039%, 0.062%, 0.017%, 0.89, 0.029 and 0.29%. This report

depicts the significance of corruption, GDP, renewable energy production, electricity consumption, and financial development in sustaining environment quality in selected Euro countries.

**Table no. 9. Kernel-based Least Squares results**

LCO2	Avg.	SE	t	P>t	P25	P50	P75
<b>LCor</b>	-0.038	0.013	-2.915	0.004	-0.244	-0.078	0.139
<b>LGDPpc</b>	-0.092	0.023	-4.061	0.000	-0.233	-0.069	0.062
<b>LREP</b>	0.008	0.001	8.171	0.000	-0.001	0.008	0.017
<b>EC</b>	0.608	0.009	65.804	0.000	0.305	0.643	0.89
<b>LGFCF</b>	0.006	0.005	1.223	0.222	-0.019	0.002	0.029
<b>FD</b>	0.125	0.051	2.436	0.015	-0.06	0.086	0.29
				<b>Diagnostics</b>			
<b>Observation</b>	722	Lambda	0.366	Tolerance	0.722	Sigma	7
<b>Eff.df</b>	85.15	R <sub>2</sub>	0.984	Looseless	25.75		

**Conclusions**

We proposed and evaluated a new developed framework to examine the moderating role of corruption on the relationship between economic growth and CO<sub>2</sub> emissions along with renewable energy production, electricity consumption, gross fixed capital formation, and financial development covering 19 Euro-countries by evaluating the long time period historical data from 1984 to 2021. The panel ARDL and KRLS estimation approaches were applied to examine the real-time impact of growth-emission.

The empirical findings depict that corruption does not moderately influence the CO<sub>2</sub> emission-economic growth nexus due to the strict policy of Euro countries to rheostat corruption along with the growth and environmental quality. However, gross fixed capital formation and renewable energy production uncontaminated and contaminated the environmental quality, respectively. The average, 25th, 50th, and 75th percentiles are used to evaluate heterogeneous marginal effects using regressor derivatives. The mean pointwise marginal impacts of corruption on GDP, renewable energy generation, electricity consumption, gross fixed capital formation, and financial development are seen to be -.038%, -0.092%, 0.08%, 0.608%, -0.006 and 0.125%, respectively. It suggests that regressors can affect the CO<sub>2</sub> emissions by 0.984%.

In light of the result, we suggest some policy ramifications. Regarding the creation of renewable energy, this energy should come from renewable sources that emit little, such as the sun and the wind. For instance, solar power offers important ecological benefits. The major advantage of solar energy is that it is a reliable and unpolluted energy source because it does not create waste or contaminate the environment. Wind energy is yet another environmentally responsible and renewable resource. It does not pollute the environment or require water to cool. Additionally, wind turbines do not emit any greenhouse gases. Further education should be provided to the private sector, and administrative obstacles to investment should be removed. The usage of these sustainable energy sources should be increased, and governments should create laws to reduce their dependence on foreign sources.

According to our findings, more study on the panel of other developed nations or a single country estimation is required. The CO<sub>2</sub> emission-growth nexus is moderately infused with corruption when the environmental quality is neglected, as is confirmed by both earlier research and our analysis. Therefore, the panel should consider other developing nations for future studies. Despite this, the use of new estimating techniques, like the Quantile family, is encouraged in order to provide results that are more productive and ahead of the curve in terms of policy.

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### References

- Abbasi, K.R. and Adedoyin, F.F., 2021. Do energy use and economic policy uncertainty affect CO<sub>2</sub> emissions in China? Empirical evidence from the dynamic ARDL simulation approach. *Environmental Science and Pollution Research*, [e-journal] 28, pp. 23323-23335. <https://doi.org/10.1007/s11356-020-12217-6>.
- Adebayo, T.S. and Beton Kalmaz, D., 2021. Determinants of CO<sub>2</sub> emissions: empirical evidence from Egypt. *Environmental and Ecological Statistics*, [e-journal] 28, pp. 239-262. <https://doi.org/10.1007/s10651-020-00482-0>.
- Akhbari, R. and Nejati, M., 2019. The effect of corruption on carbon emissions in developed and developing countries: empirical investigation of a claim. *Heliyon*, [e-journal] 5, no. art.e02516. <https://doi.org/10.1016/j.heliyon.2019.e02516>.
- Anwar, A., Sinha, A., Sharif, A., Siddique, M., Irshad, S., Anwar, W. and Malik, S., 2022. The nexus between urbanization, renewable energy consumption, financial development, and CO<sub>2</sub> emissions: evidence from selected Asian countries. *Environment, Development and Sustainability*, [e-journal] 24, pp. 6556-6576. <https://doi.org/10.1007/s10668-021-01716-2>.
- Appiah, K., Du, J., Yeboah, M. and Appiah, R., 2019. Causal correlation between energy use and carbon emissions in selected emerging economies-panel model approach. *Environmental Science and Pollution Research*, [e-journal] 26, pp. 7896-7912. <https://doi.org/10.1007/s11356-019-04140-2>.
- Bhattacharya, M., Awaworyi Churchill, S. and Paramati, S.R., 2017. The dynamic impact of renewable energy and institutions on economic output and CO<sub>2</sub> emissions across regions. *Renewable Energy*, [e-journal] 111, pp. 157-167. <https://doi.org/10.1016/j.renene.2017.03.102>.
- Cadoret, I. and Padovano, F., 2016. The political drivers of renewable energies policies. *Energy Economics*, [e-journal] 56, pp. 261-269. <https://doi.org/10.1016/j.eneco.2016.03.003>.



- Cerdeira Bento, J.P. and Moutinho, V., 2016. CO<sub>2</sub> emissions, non-renewable and renewable electricity production, economic growth, and international trade in Italy. *Renewable and Sustainable Energy Reviews*, [e-journal] 55, pp. 142-155. <https://doi.org/10.1016/j.rser.2015.10.151>.
- Chen, H., Tackie, E.A., Ahakwa, I., Musah, M., Salakpi, A., Alfred, M. and Atingabili, S., 2022. Does energy consumption, economic growth, urbanization, and population growth influence carbon emissions in the BRICS? Evidence from panel models robust to cross-sectional dependence and slope heterogeneity. *Environmental Science and Pollution Research*, [e-journal] 29, pp. 37598-37616. <https://doi.org/10.1007/s11356-021-17671-4>.
- Chen, Y., Wang, Z. and Zhong, Z., 2019. CO<sub>2</sub> emissions, economic growth, renewable and non-renewable energy production and foreign trade in China. *Renewable Energy*, [e-journal] 131, pp. 208-216. <https://doi.org/10.1016/j.renene.2018.07.047>.
- Doğanlar, M., Mike, F., Kızılkaya, O. and Karlılar, S., 2021. Testing the long-run effects of economic growth, financial development and energy consumption on CO<sub>2</sub> emissions in turkey: new evidence from rals cointegration test. *Environmental Science and Pollution Research*, [e-journal] 28, pp. 32554-32563. <https://doi.org/10.1007/s11356-021-12661-y>.
- Ertugrul, H.M., Cetin, M., Seker, F. and Dogan, E., 2016. The impact of trade openness on global carbon dioxide emissions: evidence from the top ten emitters among developing countries. *Ecological Indicators*, [e-journal] 67, pp. 543-555. <https://org/10.1016/j.ecolind.2016.03.027>.
- Fredriksson, P.G., Vollebergh, H.R.J. and Dijkgraaf, E., 2004. Corruption and energy efficiency in OECD countries: theory and evidence. *Journal of Environmental Economics and Management*, [e-journal] 47, pp. 207-231. <https://doi.org/10.1016/j.jeem.2003.08.001>.
- Grossman, G.M. and Krueger, A.B., 1995. Economic growth and the environment. *The Quarterly Journal of Economics*, [e-journal] 110, pp. 353-377. <https://doi.org/10.2307/2118443>.
- Habib, S., Abdelmonem, S. and Khaled, M., 2020. The effect of corruption on the environmental quality in African countries: a panel quantile regression analysis. *Journal of the Knowledge Economy*, [e-journal] 11, pp. 788-804. <https://doi.org/10.1007/s13132-018-0571-8>.
- Haseeb, M. and Azam, M., 2021. Dynamic nexus among tourism, corruption, democracy and environmental degradation: a panel data investigation. *Environment, Development and Sustainability*, [e-journal] 23, pp. 5557-5575. <https://doi.org/10.1007/s10668-020-00832-9>.
- Inglesi-Lotz, R. and Dogan, E., 2018. The role of renewable versus non-renewable energy to the level of CO<sub>2</sub> emissions a panel analysis of sub-Saharan Africa's big 10 electricity generators. *Renewable Energy*, [e-journal] 123, pp. 36-43. <https://doi.org/10.1016/j.renene.2018.02.041>.
- Islam, M.M., Khan, M.K., Tareque, M., Jehan, N. and Dagar, V., 2021. Impact of globalization, foreign direct investment, and energy consumption on CO<sub>2</sub> emissions in bangladesh: does institutional quality matter? *Environmental Science and Pollution Research*, [e-journal] 28, pp. 48851-48871. <https://doi.org/10.1007/s11356-021-13441-4>.
- Jiang, Q., Khattak, S.I. and Rahman, Z.U., 2021. Measuring the simultaneous effects of electricity consumption and production on carbon dioxide emissions (CO<sub>2</sub>e) in China: new evidence from an EKC-based assessment. *Energy*, [e-journal] 229, no. art.120616. <https://doi.org/10.1016/j.energy.2021.120616>.

- Khan, M. and Ozturk, I., 2021. Examining the direct and indirect effects of financial development on CO<sub>2</sub> emissions for 88 developing countries. *Journal of Environmental Management*, [e-journal] 293, no. art.112812. <https://doi.org/10.1016/j.jenvman.2021.112812>.
- Khezri, M., Karimi, M.S., Khan, Y.A. and Abbas, S.Z., 2021. The spillover of financial development on CO<sub>2</sub> emission: a spatial econometric analysis of Asia-Pacific countries. *Renewable and Sustainable Energy Reviews*, [e-journal] 145, no. art.111110. <https://doi.org/10.1016/j.rser.2021.111110>.
- Lv, Z. and Li, S., 2021. How financial development affects CO<sub>2</sub> emissions: a spatial econometric analysis. *Journal of Environmental Management*, [e-journal] 277, no. art.111397. <https://doi.org/10.1016/j.jenvman.2020.111397>.
- Masron, T.A. and Subramaniam, Y., 2018. The environmental Kuznets curve in the presence of corruption in developing countries. *Environmental Science and Pollution Research*, [e-journal] 25, pp. 12491-12506. <https://doi.org/10.1007/s11356-018-1473-9>.
- Mostafaeipour, A., Bidokhti, A., Fakhrzad, M.-B., Sadegheih, A. and Zare Mehrjerdi, Y., 2022. A new model for the use of renewable electricity to reduce carbon dioxide emissions. *Energy*, [e-journal] 238, no. art.121602. <https://doi.org/10.1016/j.energy.2021.121602>.
- Mujtaba, A. and Jena, P.K., 2021. Analyzing asymmetric impact of economic growth, energy use, FDI inflows, and oil prices on CO<sub>2</sub> emissions through NARDL approach. *Environmental Science and Pollution Research*, [e-journal] 28, pp. 30873-30886. <https://doi.org/10.1007/s11356-021-12660-z>.
- Mujtaba, A., Jena, P.K., Bekun, F.V. and Sahu, P.K., 2022. Symmetric and asymmetric impact of economic growth, capital formation, renewable and non-renewable energy consumption on environment in OECD countries. *Renewable and Sustainable Energy Reviews*, [e-journal] 160, no. art.112300. <https://doi.org/10.1016/j.rser.2022.112300>.
- Oláh, J., Popp, J., Duleba, S., Kiss, A. and Lakner, Z., 2021. Positioning Bio-Based Energy Systems in a Hypercomplex Decision Space—A Case Study. *Energies*, [e-journal] 14(14), p.4366. <https://doi.org/10.3390/en14144366>.
- Omri, A., 2014. An international literature survey on energy-economic growth nexus: evidence from country-specific studies. *Renewable and Sustainable Energy Reviews*, [e-journal] 38, pp. 951-959. <https://doi.org/10.1016/j.rser.2014.07.084>.
- Paramati, S.R., Mo, D. and Gupta, R., 2017. The effects of stock market growth and renewable energy use on CO<sub>2</sub> emissions: evidence from G20 countries. *Energy economics*, [e-journal] 66, pp. 360-371. <https://doi.org/10.1016/j.eneco.2017.06.025>.
- Pei, Y., Zhu, Y. and Wang, N., 2021. How do corruption and energy efficiency affect the carbon emission performance of China's industrial sectors? *Environmental Science and Pollution Research*, [e-journal] 28, pp.31403-31420. <https://doi.org/10.1007/s11356-021-13032-3>.
- Pesaran, M.H., 2004. General diagnostic tests for cross section dependence in panels. Cambridge: Cambridge University.
- Pesaran, M.H., 2007. A simple panel unit root test in the presence of cross-section dependence. *Journal of Applied Econometrics*, [e-journal] 22, pp. 265-312. <https://doi.org/10.1002/jae.951>.

- Pesaran, M.H. and Smith, R., 1995. Estimating long-run relationships from dynamic heterogeneous panels. *Journal of Econometrics*, [e-journal] 68, pp. 79-113. [https://doi.org/10.1016/0304-4076\(94\)01644-f](https://doi.org/10.1016/0304-4076(94)01644-f).
- Rahaman, M., Hossain, M. and Chen, S., 2022. The impact of foreign direct investment, tourism, electricity consumption, and economic development on CO<sub>2</sub> emissions in Bangladesh. *Environmental science and pollution research*, [e-journal] 29, pp.37344-37358. <https://doi.org/10.1007/s11356-021-18061-6>.
- Rahman, Z.U. and Ahmad, M., 2019. Modeling the relationship between gross capital formation and CO<sub>2</sub> (a)symmetrically in the case of Pakistan: an empirical analysis through NARDL approach. *Environmental Science and Pollution Research*, [e-journal] 26, pp. 8111-8124. <https://doi.org/10.1007/s11356-019-04254-7>.
- Ren, S., Yuan, B., Ma, X. and Chen, X., 2014. International trade, FDI (foreign direct investment) and embodied CO<sub>2</sub> emissions: a case study of Chinas industrial sectors. *China Economic Review*, [e-journal] 28, pp. 123-134. <https://doi.org/10.1016/j.chieco.2014.01.003>.
- Schmiedeknecht, M.H., 2013. Environmental sustainability index. *Encyclopedia of Corporate Social Responsibility*, pp. 1017-1024.
- Sek, S.K., Sim, K.Y., Chea, W.K. and Hoe, Z.H., 2022. The causal nexus between government expenditure and economic growth: Wagner versus Keynes hypothesis. *Matematika: Malaysian Journal of Industrial and Applied Mathematics*, 38(2), pp. 91-102.
- Shahbaz, M., Sharma, R., Sinha, A. and Jiao, Z., 2021. Analyzing nonlinear impact of economic growth drivers on CO<sub>2</sub> emissions: designing an SDG framework for India. *Energy Policy*, [e-journal] 148, 111965. <https://doi.org/10.1016/j.enpol.2020.111965>.
- Sinha, A., Gupta, M., Shahbaz, M. and Sengupta, T., 2019. Impact of corruption in public sector on environmental quality: implications for sustainability in BRICS and next 11 countries. *Journal of Cleaner Production*, [e-journal] 232, pp. 1379-1393. <https://doi.org/10.1016/j.jclepro.2019.06.066>.
- Wang, Z., Danish, Zhang, B. and Wang, B., 2018. The moderating role of corruption between economic growth and CO<sub>2</sub> emissions: evidence from BRICS economies. *Energy*, [e-journal] 148, pp. 506-513. <https://doi.org/10.1016/j.energy.2018.01.167>.
- Yao, S., Zhang, S. and Zhang, X., 2019. Renewable energy, carbon emission and economic growth: a revised environmental Kuznets curve perspective. *Journal of Cleaner Production*, [e-journal] 235, pp. 1338-1352. <https://doi.org/10.1016/j.jclepro.2019.07.069>.
- You, W., Zhang, Y. and Lee, C.-C., 2022. The dynamic impact of economic growth and economic complexity on CO<sub>2</sub> emissions: an advanced panel data estimation. *Economic Analysis and Policy*, [e-journal] 73, pp. 112-128. <https://doi.org/10.1016/j.eap.2021.11.004>.
- Yurtkuran, S., 2021. The effect of agriculture, renewable energy production, and globalization on CO<sub>2</sub> emissions in turkey: a bootstrap ARDL approach. *Renewable Energy*, [e-journal] 171, pp. 1236-1245. <https://doi.org/10.1016/j.renene.2021.03.009>.