frontiers | Frontiers in Environmental Science

TYPE Original Research
PUBLISHED 05 January 2023
DOI 10.3389/fenvs.2022.1074172



EDITED BY
Mobeen Ur Rehman,
Shaheed Zulfikar Ali Bhutto Institute of Science and Technology (SZABIST), United Arab Emirates

REVIEWED BY
Ugur Korkut Pata,
Osmaniye Korkut Ata University, Türkiye
Nor Ermavati Hussain,
University of Malaysia Terengganu, Malaysia

*CORRESPONDENCE
Amin Pujiati,
amin.pujiati@mail.unnes.ac.id
Abdul Rahim Ridzuan,
Rahim670@uitm.edu.my

SPECIALTY SECTION
This article was submitted to Environmental Economics and Management,
a section of the journal
Frontiers in Environmental Science

RECEIVED 19 October 2022
ACCEPTED 14 December 2022
PUBLISHED 05 January 2023

CITATION
Pujiati A, Yanto H, Dwi Handayani B, Ridzuan AR, Borhan H and Shaari MS (2023), The detrimental effects of dirty energy, foreign investment, and corruption on environmental quality: New evidence from Indonesia.
*Front. Environ. Sci.* 10:1074172.
doi: 10.3389/fenvs.2022.1074172



# The detrimental effects of dirty energy, foreign investment, and corruption on environmental quality: New evidence from Indonesia

Amin Pujiati[1]*, Heri Yanto[1], Bestari Dwi Handayani[1], Abdul Rahim Ridzuan[2,3,4,5,6]*, Halimahton Borhan[2] and Mohd Shahidan Shaari[7]

[1]Faculty of Economics, Universitas Negeri Semarang, Semarang, Indonesia, [2]Faculty of Business and Management, Universiti Teknologi MARA, Shah Alam, Malaysia, [3]Faculty of Economics and Business, Universitas Negeri Malang, Malang, Indonesia, [4]Institute for Big Data Analytics and Artificial Intelligence, Universiti Teknologi MARA, Shah Alam, Malaysia, [5]Centre for Economic Development and Policy, Universiti Malaysia Sabah, Kota Kinabalu, Malaysia, [6]Institute for Research on Socio Economic Policy, Universiti Teknologi MARA, Shah Alam, Malaysia, [7]Faculty of Business and Communication, Universiti Malaysia Perlis, Arau, Malaysia

The alarming trend of $CO_2$ emissions in Indonesia merits a reinvestigation into the determinants in a bid to conserve the environment. In the literature, in Indonesia, three potential determinants, namely, energy, foreign direct investment, and corruption, have been identified to harm the environment. However, their effects are still undetermined. Thus, this study aims to examine the relationships between corruption (COR), energy use (ENY), foreign direct investment (FDI), and $CO_2$ emissions in Indonesia. The autoregressive distributed lag (ARDL) approach was used to analyse data for 36 years, from 1984 to 2020. The results reveal that corruption contributes to greater environmental degradation in the short run, while foreign direct investment does not. However, in the long run, corruption and energy use can positively affect environmental degradation, but foreign direct investment can reduce environmental degradation in Indonesia. This study also found two other factors, namely, economic growth and urbanisation, which can affect the environment with mixed findings. These findings are indispensable for policy formulation in Indonesia as Indonesia is a rapidly developing country that depends on good environmental quality to ensure future growth and sustainable development.

KEYWORDS
**$CO_2$ emissions, foreign direct investment, corruption, energy use, environmental quality**

## 1 Introduction

In the last few decades, developing countries have progressed rapidly. They have transformed from agriculture to industrialisation, boosting economic growth and improving people's living standards. In Indonesia, the change of power from the old order regime to the new order has transformed Indonesia's economic policy. Since the 1980s, Indonesia has sought to boost economic growth, leading to a higher energy use and rapid urbanisation. Moreover, the country has successfully attracted higher foreign direct investment (FDI) through numerous government incentives and tax reforms. Figure 1 shows the growth of Indonesia's gross

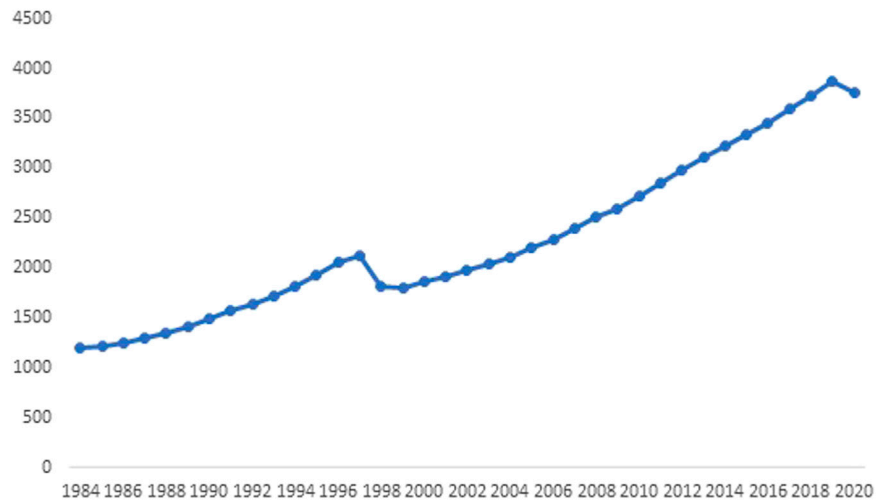


FIGURE 1
Trend of per capita (constant price 2005) in Indonesia (US dollar), 1984–2020.

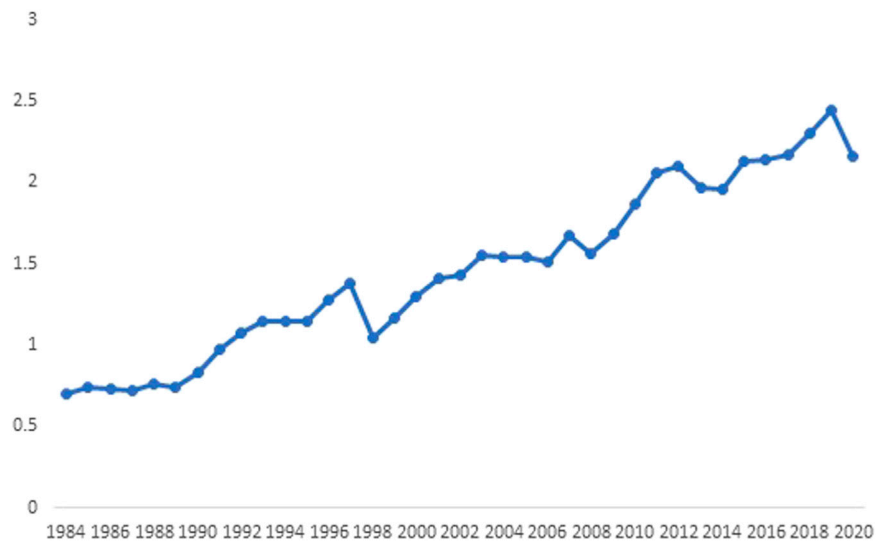


FIGURE 2
Trend of $CO_2$ emission in Indonesia, 1984–2020 (metrics *per capita*).

domestic product (*per capita* 2005) from 1984 to 2020. The value of GDP *per capita* in 1984 stood at 1,204 US dollars, and it tripled in 2020 to 3,757 US dollars. This condition shows a significant increase in the prosperity and welfare of the people. The rapid growth in the industrial and manufacturing sectors that contributed towards the country's GDP, however, has caused detrimental effects on the environmental quality in Indonesia (Pujiati et al., 2020).

The development strategies that Indonesia implemented to accelerate the economic performance were supported by population growth and the improvement of urban communities. This, however, has raised an important issue: environmental pollution (Sehrawa et al., 2015). The impact of unmoderated development and technological progress has pushed the country to face sustainable development challenges, such as environmental degradation, climate change, and exploitation of natural resources (Koshta et al., 2021). Rahman (2020) stated that economic growth requires additional production from an industry, and the additional energy consumption is unavoidable, which drives carbon emissions. Alam (2022) argued that the requirements for an increased economic growth undermined the environmental quality in developing countries, leaving a long-lasting impact on development and industrialisation. Although the Indonesian government has introduced sustainable development plans, the level of carbon emission still increases as the country continues to rely on dirty energies, such as coal and fossil fuels, to keep up with the increasing demand.

Figure 2 shows an increase of 2.09% in $CO_2$ emissions from 1984 to 2020. The value of $CO_2$ emissions in 1984 was only 0.7 metrics *per capita* and reached 2.16 metrics *per capita* in 2020.

Population growth and urbanisation can increase $CO_2$ emissions in developing countries (Ansari et al., 2019) as more people are attracted to urban areas because of their development (Pujiati et al., 2019). Due to urbanisation, the country has developed better infrastructure that attracts more foreign investors to run their businesses there. However, in the presence of foreign investment, environmental degradation may either increase or decrease.

Danmaraya and Danlami (2021) stated that the driving factor for $CO_2$ emissions is foreign direct investment, which has different impacts on environmental quality through composition, engineering, and scale effects. The composition effect concludes that FDI can increase or decrease pollution by changing the economic patterns. However, the effect of scale states that FDI harms the environment by increasing the size of the country's economy. Meanwhile, the engineering effect states that foreign companies can adopt more environmental friendly technologies and improve the environment by reducing emissions. Munir and Ameer (2019) stated that FDI brings inappropriate technology, which is the primary source of pollution. Capital inflows into a country can have a major impact on the environment, depending on the type of technology used and rules and regulations on environmental protection (Panait et al., 2022). Many researchers have found that FDI positively affects $CO_2$ emissions in lower-middle countries (Hassaballa, 2014; Paramati et al., 2016; Danlami et al., 2019). However, the findings of studies that investigated the relationship between FDI and environmental degradation in Indonesia remain inconclusive. In addition, good governance can also affect the environmental quality.

Sustainable development must be supported by good governance. In pursuing long-term sustainable growth, state institutions should adopt efficient practices and implement ethical and responsible actions to achieve long-term strategic goals. Community supervision is essential to avoid unethical and irresponsible actions. Corruption is a global problem with power that can affect all countries and all sectors of activity (Sekrafi and Sghaier, 2017). A high level of corruption indicates incompetent governance. The issue of corruption and environmental degradation in Indonesia has become a major concern in recent years. The prevalent corruption has resulted in the high exploitation of natural resources and massive environmental damage. The use of dirty energy may increase in the presence of corruption. Muslihudin et al. (2018) explained that there are three situations when corruption can happen and thus harm the environment: 1) when licencing from entrepreneurs to regional heads, 2) when granting environmental impact analysis licences, and 3) when imposing fees on entrepreneurs that can cause higher costs. Indonesia's Corruption Perceptions Index (CPI) in 1984 was 1.00 and increased to 3.00 in 2020, indicating greater corruption and thus merits serious attention. Ganda (2020) found that the corrupt behaviour using two indices, namely, the corruption index and corruption rankings, has worsened environmental sustainability in 16 countries in Southern Africa. Cole and Fredriksson (2009) found that countries with weak environmental institutions will attract more polluting industries that encourage environmental damage.

Due to the mixed findings on the impact of energy use, FDI, and corruption on the environment in other countries, it is still important to reinvestigate the effects of energy use, foreign direct investment, and corruption on the environment in Indonesia from 1984 to 2020. The structure of this paper consists of Section 1: Introduction, Section 2: Literature review, Section 3: Methodology, Section 4: Results and discussion, and Section 5: Conclusions and policy implications.

## 2 Literature review

On a theoretical level, Antweiler et al.'s (2004) model indicates that, through specialisation and exchanges, rich countries concerned about the quality of their environment should relocate polluting activities to developing countries, which are generally characterised by less stringent environmental regulations. Numerous researchers from various countries or regions have discovered a link between economic growth and environmental degradation. The results vary depending on the sample size and the time period studied (Koengkan et al., 2019a; Chishti et al., 2021; Qin et al., 2021). Many researchers have used the environmental Kuznets curve (EKC) hypothesis to investigate the relationship between economic growth and environmental quality (Yilanci and Pata, 2020). The theory's validity has been demonstrated in several countries, including the United States (Atasoy, 2017), Pakistan (Rehman et al., 2021a), Malaysia (Nurgazina et al., 2021), China (Pata and Caglar, 2021), and the OECD (Cao et al., 2022). On the other hand, some studies have been unable to establish a link between economic growth and environmental degradation. For example, Zambrano-Monserrate et al. (2018) investigated the Peruvian nexus and discovered that the findings do not support the EKC hypothesis. Another study on South Korea by Koc and Bulus (2020) found evidence of an N-shaped relationship between economic growth and environmental degradation, invalidating the EKC theory.

Some studies have investigated the relationship between energy consumption and environmental degradation, particularly $CO_2$ emissions (Khan, Hou and Le, 2021). Wasti and Zaidi (2020) found a link between energy consumption and environmental degradation in Kuwait. Adebayo and Akinsola (2021) revealed a bidirectional link between environmental degradation and energy consumption in Thailand using the wavelet coherence method, classical Granger, and Toda–Yamamoto causality approaches. In addition, Ahmed et al. (2017), Aye and Edoja (2017), and Musah et al. (2021) identified energy consumption as a major contributor to $CO_2$ emissions in five South Asian countries, 31 emerging economies, and North Africa, respectively.

Because the ARDL model has produced significant results in other fields, many scholars have applied it to the study of environmental economics to investigate the long-term and short-term relationships between related variables. Bosah et al. (2021) examined the panel data from 15 countries on energy consumption, economic growth, urbanisation, and carbon emissions. The findings indicated that urbanisation has no significant impact on environmental quality and that energy consumption will harm the environment in the long and short run. Ali et al. (2017) and Pata (2018) investigated the relationship between urbanisation and $CO_2$ emissions in Singapore and Turkey. However, their findings are inconsistent as there is a negative relationship between urbanisation and $CO_2$ emissions in Singapore, and there is a positive relationship in Turkey. With Japanese research subjects, Ahmed et al. (2021) examined the impact of globalisation, economic growth, and financial development on a carbon footprint. The findings revealed that an increased energy consumption and financial development would substantially increase the carbon footprint. In contrast, the relationship between the economy and carbon footprint exhibited an inverted U-shaped curve, confirming the validity of EKC in Japan.

The existing literature on the relationship between corruption and environmental sustainability is active (Ganda, 2020; Wang, Zhao and Chen, 2020; Usman, 2022). According to popular beliefs, corruption can, directly and indirectly, contribute to environmental degradation (Wang, Zhao, and Chen 2020). Usman (2022), for example, used a dynamic ARDL simulation technique to investigate the effects of social and economic factors on the environmental quality in Nigeria. Although economic growth exacerbated environmental degradation in Nigeria, corruption and internal conflict mitigated environmental degradation by reducing the investment and growth. Wang, Zhao, and Chen (2020) used the system GMM on provincial panel data in China's industry from 2005 to 2015 to establish that corruption influences $CO_2$ emissions through environmental policy distortions and low monitoring levels.

Furthermore, Habib, Abdelmonen, and Khaled (2020) investigated how corruption affects $CO_2$ emissions and economic growth in Africa using a panel quantile regression method. The findings were as follows: 1) a higher level of corruption in Africa; 2) corruption is negatively related to $CO_2$ emissions in lower $CO_2$-emitting countries; 3) corruption is not a significant enough factor in higher $CO_2$-emitting countries to explain changes in $CO_2$ emissions; and 4) corruption is positively affected by $CO_2$ emissions. Because the positive effect outweighs the negative effect, the overall effect of corruption is positive.

Regarding the relationship between FDI and $CO_2$ emissions, Ahmed et al. (2022) found that developing countries, such as most African countries, adopted convenient environmental regulations for a variety of reasons, including the fact that economic growth, rather than environmental quality, is the primary goal of these countries. The study found that FDI increases $CO_2$ emissions and contributes to environmental degradation. This assertion was supported by the study of Abdouli and Hammami (2017) and Pata et al. (2022), which found that FDI positively impacts the environmental quality of developed countries while having a negative impact on the environmental quality of poor or developing countries. Using green technology, FDI, and environmental regulation, Behera and Sethi (2022) discovered that environmental regulation significantly affects green technology innovation and that FDI causes green technology innovation to decrease.

Several gaps have been found in previous studies. First, it is hard to find studies focussing on the impact of foreign investment, energy used, and corruption in Indonesia. Thus, this research's findings could contribute to the body of knowledge. In addition, this research uses the most recent sample data and sophisticated techniques to provide some insight into the robustness of the findings. The summary of empirical studies as discussed in this section can be view in Table 1.

## 3 Methodology

The IPAT model provides an equation that articulates the idea of the environmental impact (I), which is dependent on three factors, namely, population (P), affluence (A), and technology (T). The model can be written as follows:

$$I = P \cdot A \cdot T. \quad (1)$$

According to the model, environmental degradation increases as the affluence or wealth of a nation increases. Countries with rapid economic development will usually focus on boosting their economic activity, which leads to higher environmental degradation. Moreover, population growth can also contribute to harming the environment. This might be due to the higher use of non-renewable resources, such as oil and coal. Boosting a country's economy usually entails using low-cost technologies, which subsequently results in a lower quality of the environment.

Previous researchers, such as Mahmood et al. (2020), used $CO_2$ emissions as a proxy for environmental degradation, population growth as a proxy for population, GDP as a proxy for affluence, and energy use as a proxy for technology. Inspired by this model, this research reintroduces the model by including other important variables. The general functional form of the environmental quality model for Indonesia is derived as follows:

$$CO2_t = f\,(GDP_t, COR_t, ENY_t, FDI_t, UBG_t), \quad (2)$$

where *CO2t* represents the environmental quality, *GDPt* represents the economic growth, *CORt* represents corruption, *ENYt* represents the energy used, *FDIt* represents foreign direct investment inflows, and *UBGt* represents the urbanisation growth.

The variables in Eq. 3 are transformed into log-linear forms (LN). The log version of the variables will indicate the short-run and long-run elasticity. According to Shahbaz et al. (2013), the log version of the tested variables can produce a consistent and reliable estimation. The log version of the model derived from Eq. 2 can be seen as follows:

$$LNCO2_t = \delta_0 + \alpha_1 LNGDP_t + \beta_2 LNCOR_t + \sigma_3 LNENY_t + \phi_4 LNFDI_t + \tau_7 LNUBG_t + \mu_t. \quad (3)$$

A higher economic development (LNGDP) is expected to increase environmental degradation (LNCO2) or exhibit positive signs, especially in developing countries. This expected sign can be seen in past studies conducted in Malaysia, such as Ridzuan et al. (2018) and Ridzuan et al. (2019). Next, LNCOR is expected to have either a positive or negative relationship with LNCO2, depending on the government rules and integrity when managing their country. Then, LNFDI is expected to have either a positive or negative link with LNCO2 for Indonesia. Therefore, the presence of the pollution haven hypothesis is validated if the expected sign between LNFDI and LNCO2 is positive. This outcome can be seen from previous studies such as Gorus and Aslan (2019) and Caglar (2020). In contrast, if the sign is negative, it validates the existence of the pollution halo hypothesis, which was also proven by Rafindadi et al. (2018) and Balsalobre-Lorente et al. (2019a). The pollution haven hypothesis, addressed by Terzi and Pata (2019) and Pata and Amit, (2021), is a situation where foreign investors decide to invest more money into a country with less stringent environmental policies. The validation of the pollution halo hypothesis, on the other hand, is the result of the engagement of foreign companies to use better management practices and advanced technologies that result in a clean environment in the host countries. Similar to LNGDP, energy used also exhibits a positive relationship with LNCO2. Higher energy generated from the combustion of fossil fuels will lead to a higher release of carbon emissions in the country. Regarding urbanisation, some studies

TABLE 1 Summary of the literature review.

| Author | Finding |
|---|---|
| Zambrano-Monserrate et al. (2018) | There is no evidence of the EKC hypothesis |
| Koc and Bulus (2020) | Evidence of an N-shaped relationship between economic growth and environmental degradation invalidates the EKC theory |
| Wasti and Zaidi (2020) | There is a link between energy consumption and environmental degradation in Kuwait |
| Adebayo and Akinsola (2021) | There is a bidirectional link between environmental degradation and energy consumption in Thailand using the wavelet coherence method, classical Granger, and Toda–Yamamoto causality approaches |
| Ahmed et al. (2017), Aye and Edoja (2017), and Musah et al. (2021) | Energy consumption is a major contributor to $CO_2$ emissions in five South Asian countries, 31 emerging economies, and North Africa |
| Bosah et al. (2021) | Urbanisation has no significant impact on environmental quality and that energy consumption will harm the environment in both the long and short term |
| Ali et al. (2017) and Pata (2018) | Their findings differed; urbanisation in Singapore inhibits carbon emissions, whereas urbanisation in Turkey promotes carbon emissions |
| Ahmed et al. (2021) | Increased energy consumption and financial development would substantially increase the carbon footprint. In contrast, the relationship between the economy and carbon footprint exhibited an inverted U-shaped curve, confirming the validity of EKC in Japan |
| Usman (2022) | Used a dynamic ARDL simulation technique to investigate the effects of social and economic factors on environmental quality in Nigeria, while economic growth exacerbated environmental degradation in Nigeria; corruption and internal conflict mitigated environmental degradation by reducing investment and growth |
| Wang, Zhao and Chen (2020) | Corruption influences $CO_2$ emissions through environmental policy distortion and low monitoring levels |
| Habib, Abdelmonen and Khaled (2020) | 1) A higher level of corruption in Africa; 2) corruption is negatively related to $CO_2$ emissions in lower $CO_2$-emitting countries; 3) corruption is not a significant enough factor in higher $CO_2$-emitting countries to explain changes in $CO_2$ emissions; and 4) corruption is positively affected by $CO_2$ emissions. Because the positive effect outweighs the negative effect, the overall effect of corruption is positive |
| Ahmed et al. (2022) | The study found that FDI increases $CO_2$ emissions and contributes to environmental degradation and found that developing countries, such as most African countries, adopted convenient environmental regulations for various reasons, including the fact that economic growth, rather than environmental quality, is the primary goal of these countries. |
| Abdouli and Hammami (2017) | FDI positively impacts the environmental quality of developed countries while harming the environmental quality of poor or developing countries |
| Behera and Sethi (2022) | Environmental regulation significantly affects green technology innovation, and FDI causes green technology innovation to decrease |

suggest the increased population caused by urbanisation triggers an intensive urban economic activity, which leads to an increased demand for energy and carbon emissions (Ali et al., 2019). However, some studies suggest urbanisation brings about economies of scale and improves public infrastructure, reducing carbon emissions (Lin and Li, 2020). No consistent conclusions have been reached.

The ARDL model considers each of the variables in turn as the dependent variables based on the unrestricted error correction model (UECM) are stated as follows.

$$\Delta LNCO2_t = \beta_1 + \theta_0 LNCO2_{t-1} + \theta_1 LNGDP_{t-1} + \theta_2 LNCOR_{t-1} + \theta_3 LNENY_{t-1} + \theta_4 LNFDI_{t-1} + \theta_5 LNUBG_{t-1} + + \sum_{i=1}^{a} \beta_i \Delta LNCO2_{t-i} + \sum_{i=0}^{b} \gamma_i \Delta LNGDP_{t-i} + \sum_{i=0}^{c} \delta_i \Delta LNCOR_{t-i} + \sum_{i=0}^{d} \lambda_i \Delta LNENY_{t-i} + \sum_{i=0}^{e} \vartheta_i \Delta LNFDI_{t-i} + \sum_{i=0}^{f} \psi_i \Delta LNUBG_{t-i} + \upsilon_t, \tag{4}$$

$$\Delta LNGDP_t = \beta_2 + \theta_0 LNCO2_{t-1} + \theta_1 LNGDP_{t-1} + \theta_2 LNCOR_{t-1} + \theta_3 LNENY_{t-1} + \theta_4 LNFDI_{t-1} + \theta_5 LNUBG_{t-1} + + \sum_{i=1}^{a} \beta_i \Delta LNGDP_{t-i} + \sum_{i=0}^{b} \gamma_i \Delta LNCO2_{t-i} + \sum_{i=0}^{c} \delta_i \Delta LNCOR_{t-i} + \sum_{i=0}^{d} \lambda_i \Delta LNENY_{t-i} + \sum_{i=0}^{e} \vartheta_i \Delta LNFDI_{t-i} + \sum_{i=0}^{f} \psi_i \Delta LNUBG_{t-i} + \upsilon_t, \tag{5}$$

$$\Delta LNCOR_t = \beta_3 + \theta_0 LNCO2_{t-1} + \theta_1 LNGDP_{t-1} + \theta_2 LNCOR_{t-1} + \theta_3 LNENY_{t-1} + \theta_4 LNFDI_{t-1} + \theta_5 LNUBG_{t-1} + + \sum_{i=1}^{a} \beta_i \Delta LNCOR_{t-i} + \sum_{i=0}^{b} \gamma_i \Delta LNGDP_{t-i} + \sum_{i=0}^{c} \delta_i \Delta LNCO2_{t-i} + \sum_{i=0}^{d} \lambda_i \Delta LNENY_{t-i} + \sum_{i=0}^{e} \vartheta_i \Delta LNFDI_{t-i} + \sum_{i=0}^{f} \psi_i \Delta LNUBG_{t-i} + \upsilon_t, \tag{6}$$

10.3389/fenvs.2022.1074172

**TABLE 2** Sources of data.

| Variable | Description | Source |
|---|---|---|
| LNCO2 | $CO_2$ emissions (metric tons *per capita*) | WDI |
| LNGDP | GDP *per capita* (constant 2015 US$) | WDI |
| LNCOR | Corruption Perceptions Index | Transparency International |
| LNFDI | Foreign direct investment, net inflows (% of GDP) | WDI |
| LNENY | Energy use (kg of oil equivalent *per capita*) | WDI |
| LNUBG | Urban population growth (annual %) | WDI |

Note: WDI stands for World Development Indicators 2022.

**TABLE 3** Testing the ADF and PP unit roots.

| Level I(0) | ADF unit root | | PP unit root | |
|---|---|---|---|---|
| | Intercept | Intercept and trend | Intercept | Intercept and trend |
| LNCO2 | −1.320 (0) | −2.712 (0) | −1.649 (12) | −2.711 (2) |
| LNGDP | −.434 (0) | −2.426 (1) | −.434 (0) | −1.948 (1) |
| LNCOR | −1.448 (0) | −1.959 (0) | −1.762 (2) | −2.380 (2) |
| LNENY | −2.206 (0) | −1.931 (0) | −4.925 (18)*** | −1.769 (8) |
| LNFDI | −2.106 (0) | −2.211 (0) | −2.310 (2) | −2.436 (2) |
| LNUBG | −0.233 (0) | −2.246 (0) | −.191 (3) | −2.246 (0) |
| **First difference I(1)** | **ADF unit root** | | **PP unit root** | |
| | Intercept | Intercept and Trend | Intercept | Intercept and Trend |
| LNCO2 | −5.207 (1)*** | −5.269 (1)*** | −6.834 (9)*** | −7.688 (12)*** |
| LNGDP | −4.234 (0)*** | −4.142 (0)** | −4.216 (2)*** | −4.119 (2)** |
| LNCOR | −4.148 (0)*** | −4.085 (0)** | −4.162 (1)*** | −4.099 (1)** |
| LNENY | −6.222 (0)*** | −6.834 (0)*** | −6.222 (1)*** | −7.439 (12)*** |
| LNFDI | −5.358 (0)*** | −5.276 (0)*** | −5.359 (1)*** | −5.277 (1)*** |
| LNUBG | −5.917 (0)*** | −5.839 (0)*** | −5.923 (3)*** | −5.842 (3)*** |

***and ** are 1% and 5% significant levels, respectively. The optimal lag length is selected automatically using the Schwarz information Criterion (SIC) for the ADF test, and the bandwidth has been selected by using the Newey–West method for the PP test.

$$\Delta LNENY_t = \beta_4 + \theta_0 LNCO2_{t-1} + \theta_1 LNGDP_{t-1} + \theta_2 LNCOR_{t-1} + \theta_3 LNENY_{t-1} + \theta_4 LNFDI_{t-1} + \theta_5 LNUBG_{t-1} + + \sum_{i=1}^{a}\beta_i \Delta LNENY_{t-i} + \sum_{i=0}^{b}\gamma_i \Delta LNGDP_{t-i} + \sum_{i=0}^{c}\delta_i \Delta LNCOR_{t-i} + \sum_{i=0}^{d}\lambda_i \Delta LNCO2_{t-i} + \sum_{i=0}^{e}\vartheta_i \Delta LNFDI_{t-i} + \sum_{i=0}^{f}\psi_i \Delta LNUBG_{t-i} + \upsilon_t, \quad (7)$$

$$\Delta LNUBG_t = \beta_5 + \theta_0 LNCO2_{t-1} + \theta_1 LNGDP_{t-1} + \theta_2 LNCOR_{t-1} + \theta_3 LNENY_{t-1} + \theta_4 LNFDI_{t-1} + \theta_5 LNUBG_{t-1} + + \sum_{i=1}^{a}\beta_i \Delta LNUBG_{t-i} + \sum_{i=0}^{b}\gamma_i \Delta LNGDP_{t-i} + \sum_{i=0}^{c}\delta_i \Delta LNCOR_{t-i} + \sum_{i=0}^{d}\lambda_i \Delta LNENY_{t-i} + \sum_{i=0}^{e}\vartheta_i \Delta LNFDI_{t-i} + \sum_{i=0}^{f}\psi_i \Delta LNCO2_{t-i} + \upsilon_t, \quad (8)$$

where Δ is the first difference operator and *ut* is the white-noise disturbance term. Residuals for the UECM should be serially uncorrelated, and the model should be stable. This validation can be addressed with a series of diagnostic tests shown in the analysis section. The final version of the model represented in Eq. 4–Eq. 8 previously can also be viewed as an ARDL of order (a b c d e f g h i). The model indicates that environmental degradation (LNCO2) can be influenced and explained by its past values. Hence, it involves other disturbances or shocks. From the estimation of UECM, the long-run elasticity is the coefficient of the one-lagged explanatory variable (multiplied by a negative sign) divided by the coefficient of the one-lagged dependent variable.

The coefficients of the first differenced variables captured the short-run effects. The null hypothesis of no co-integration in the long-run relationship is defined by

TABLE 4 Detecting the presence of long-run co-integration based on F-statistics.

| Model | Max lag | Lag order | F-statistic | Result |
|---|---|---|---|---|
| LNCO2 = f(LNGDP, LNCOR, LNENY, LNFDI, LNUBG) | (4,4) | (1,1,0,1,0,0) | 5.929*** | Co-integration |
| LNGDP = f(LNCO2, LNCOR, LNENY, LNFDI, LNUBG) | (4,4) | (1,3,0,1,1,0) | 3.534* | Co-integration |
| LNCOR = f(LNCO2, LNGDP, LNENY, LNFDI, LNUBG) | (4,4) | (4,3,4,4,4,4) | 3.854** | Co-integration |
| LNENY = f(LNCO2, LNGDP, LNCOR, LNFDI, LNUBG) | (4,4) | (1,0,0,0,0,0) | 1.400 | No co-integration |
| LNFDI = f(LNCO2, LNGDP, LNCOR, LNENY, LNUBG) | (4,4) | (4,3,4,4,4,4) | 5.724*** | Co-integration |
| LNUBG = f(LNCO2, LNGDP, LNCOR, LNENY, LNFDI) | (2,2) | (1,0,0,2,0,0) | 2.833 | No co-integration |
| Critical values for F-statistics | | Lower I(0) | Upper (1) | |
| 10% | | 2.26 | 3.35 | |
| 5% | | 2.62 | 3.79 | |
| 1% | | 3.41 | 4.68 | |

Note: 1. k is the number of variables, and it is equivalent to 5.2. *, **, and *** represent 10%, 5%, and 1% levels of significance, respectively. Estimation is based on the Schwarz Criterion (SC).

TABLE 5 Diagnostic tests.

| (A) Serial correlation [*p*-value] | (B) Functional form [*p*-value] | (C) Normality [*p*-value] | (D) Heteroscedasticity [*p*-value] |
|---|---|---|---|
| 0.356 | 1.241 | 1.249 | 0.878 |
| [0.703] | [0.275] | [0.535] | [0.547] |

Note. 1. ** represent 5% significant levels.
2. The diagnostic test is performed as follows: A, Lagrange multiplier test for residual serial correlation; B, Ramsey's RESET test using the square of the fitted values; C, based on a test of skewness kurtosis of residuals; D, based on the regression of squared fitted values.

H0: θ0=θ1=θ2=θ3=θ4=θ5=0 (there is no long-run relationship) is tested against the alternative of

H1: θ0≠θ1≠θ2≠ θ3≠θ4≠θ5≠0 (a long-run relationship exists), employing the familiar F-test, suppose the computed F-statistic is less than the lower-bound critical value. In that case, we do not reject the null hypothesis of no co-integration. However, suppose the computed F-statistics is greater than the upper-bound critical value of at least the 10% significant level. In that case, we reject the null hypothesis of no co-integration.

In this work, we aimed to test the dynamic linkages between the potential indicators for Indonesia's environmental quality, where the previous literature using panel data analysis has presented mixed and ambiguous evidence for each nation (Hossain, 2011). To get around some of the issues with panel data analysis, we used the time series analysis in our study. Furthermore, to deliver reliable results, country-specific analyses like this study are required (Chandran et al., 2010). In addition, our study strongly emphasises the causal links between FDI and $CO_2$ emissions, which gives us less insight into the pollution haven theory. According to the previous literature, FDI may increase global $CO_2$ emissions if environmental regulations are loosened in developing nations (Pao & Tsai, 2011).

This study uses the annual data ranging from 1984 up to 2020 (36 years) as a sample period. A summary of the data and its sources is shown in Table 2.

# 4 Result and discussion

The stationarity of the data needs to be tested to identify the right co-integration analysis for time series data. The stationarity analysis is performed by using ADF and PP unit roots. The outcomes can be viewed in Table 3. Based on the ADF unit root, it is found that all variables are not stationary at any level. However, all variables are found to be stationary at a 1 or 5% significant level at the first difference. We proceed to the PP unit root test to reconfirm the stationarity of each variable. The PP unit root is more powerful than the ADF unit root. Overall, we found that LNENY is stationary at the 1% significant level, while the remaining variables are not significant. However, as we proceed to the first difference, all variables are found to be significant either at a 1 or 5% significant level. The mix stationarity outcome fulfils the condition for ARDL testing for the model proposed in this study.

In examining the long-run relationship between $CO_2$ and its determinants, we proceed to the bounds-testing approach for all possible models, and the results are reported in Table 4. The computed F-statistics for $CO_2$, GDP, COR, and FDI equations suggest the rejection of the null hypothesis of no co-integration. The F statistic from this model is significant between the 1% and 10% significant level. However, the null hypothesis is not rejected for other equations. We can proceed to the long-run and short-run estimations based on the main model, and the following analysis will be solely performed on this model.

Before proceeding to the primary outcomes, we must ensure that the model we run has passed all diagnostic tests. Among the diagnostic tests we performed are serial correlation, functional form, normality, heteroscedasticity, and stability model consisting of CUSUM and CUSUMSQ tests. Based on Table 5, it is confirmed that the carbon emissions model that we focus on in this study has

10.3389/fenvs.2022.1074172

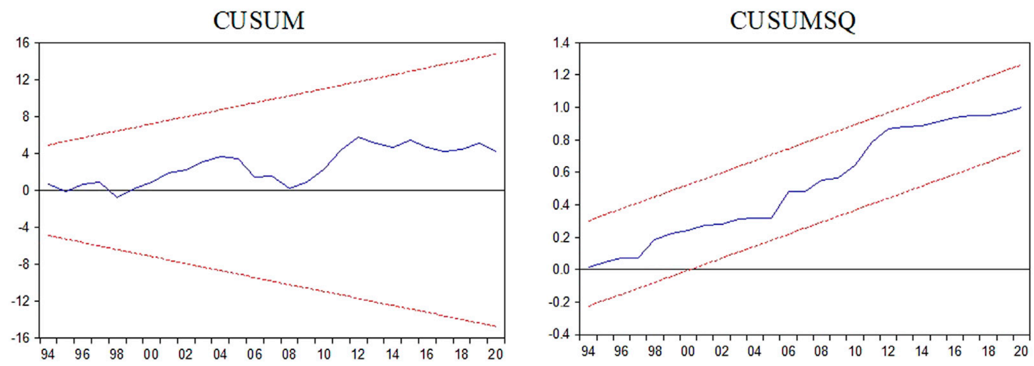


FIGURE 3
CUSUM and CUSUMSQ.

**TABLE 6 Short-run and long-run elasticities.**

| Short-run elasticity | | Long-run elasticity | |
|---|---|---|---|
| Variable | Coefficient | Variable | Coefficient |
| D(LNGDP) | 1.275*** | LNGDP | 0.309* |
| D(LNCOR) | 0.064* | LNCOR | 0.088* |
| D(LNENY) | −0.018 | LNENY | 0.639*** |
| D(LNFDI) | −0.021 | LNFDI | −0.029* |
| D(LNUBG) | −0.170 | LNUBG | −0.232 |
| CointEq(-1) | −0.731*** | C | −6.039*** |

Note: 1. ***, **, and * are 1%, 5%, and 10% significant levels, respectively.
2. Δ refers to difference.

passed all the diagnostic tests, as shown in Table 4. The probability value for the first four tests is more than the 10% significance level, thus confirming that the model is free from serial correlation problems, is functioning well, is normally distributed, and has no heteroscedasticity problem.

We also performed CUSUM and CUSUMSQ tests to ensure the stability of the model. Based on Figure 3, the blue line is in between the two red lines, thus confirming that the model is reliable.

Table 6 shows the main analysis based on short- and long-run elasticities. As for the short-run outcomes, we found out that both LNGDP and LNCOR have a positive association with environmental degradation in Indonesia. Statistically, 1% increase in LNGDP and LNCOR leads to 1.28% and 0.01% increase in carbon emissions releases. Rapid development in the country causes more pollution than governance. Meanwhile, other variables such as LNENY, LNFDI, and LNUBG are not significant at any level, thus not affecting environmental degradation in the short run. The estimated lagged ECT in ARDL regression for this model appears to be negative and statistically significant. Based on the ECT value, the adjustment speed was obtained at 0.731. For instance, this value indicated that more than 73% of adjustments were completed within less than a year, and all the variables converge; thus, the outcome for long-run elasticities will provide a meaningful input for the policymakers.

The long-run elasticities are explained as follows: the relationship between economic growth and $CO_2$ emissions is positive and significant at 10%. Keeping other things the same, a 1% increase in economic growth increases $CO_2$ emissions by 0.31%. This outcome is similar to the previous research performed by Shahbaz et al. (2013) and Sugiawan and Managi (2016). Our empirical findings indicate that economic growth is the second largest contributor to $CO_2$ emissions in the case of Indonesia. Our empirical exercise indicates that energy use (LNENY) is the largest contributor to carbon emission in the case of Indonesia. A 1% increase in LNENY leads to a 0.64% increase in carbon emissions. Indonesia's economy still relies heavily on coal as a cheaper energy source for economic development; however, it has degraded the climate quality (Ridzuan et al., 2021; Ahmed F. et al., 2022; Hongqiao et al., 2022). Systemic corruption in Indonesia has a long-term worsening effect on environmental degradation. Statistically, a 1% increase in LNCOR led to an increase of 0.09% in carbon emission. This finding supports the previous findings by Akali et al. (2021), where corruption positively affects environmental pollution. The rise of corruption may lead to an extension of economic activities by short-circuiting the bureaucratic process, which triggers more resource utilisation and leads to environmental destruction.

Furthermore, the weakening to implement environmental regulations because of corruption is one of the main reasons for lacking environmental targets (Balsalobre-Lorente et al., 2019b). The corruption level could hinder the country's progress towards achieving environmental sustainability. The only favoured outcome from this model is LNFDI. The results reveal that LNFDI has a negative relationship with LNCO2. Technically, a 1% increase in LNFDI decreases LNCO2 emissions by 0.03%. This outcome validates the halo effect hypothesis, where a higher level of foreign direct investment focussing on green and clean technology helps the nation curb industrial emissions. This result is in line with the studies performed by Rafindadi et al. (2018).

## 5 Conclusion and policy implications

This study aims to analyse the dynamic linkages between GDP, corruption, energy use, FDI, and urbanisation on $CO_2$ emissions in Indonesia. This study uses an autoregressive distributed lag (ARDL) to measure the short-run and long-run elasticities among the tested variables. Based on the short run, the variables that affect $CO_2$ emissions in Indonesia are GDP and corruption. GDP and corruption have a positive effect on $CO_2$ emissions. Energy use, foreign investment, and urbanisation have no effect on $CO_2$ emissions. In the long run, the variables that affect $CO_2$ emissions are GDP, corruption, energy use, and FDI. Urbanisation, in the long run, however, does not affect $CO_2$ emissions. GDP, corruption, and energy use have a positive effect, while FDI harms $CO_2$ emissions in Indonesia.

The findings of this study are important for policy implications. Economic development in Indonesia can lead to environmental degradation. This problem is common in most countries as pursuing sustainable development is difficult. However, it is possible if the government is serious about achieving the sustainability that the United Nations has promoted. Policymakers must ensure that new development projects implemented by developers must follow environmental regulations, or they have to consider green development in their projects. The imposition of environmental taxes is ineffective as developers can still harm the environment if willing to pay higher taxes.

The heavy reliance on dirty energies should come to an end. Policymakers must emphasise exploring clean and renewable energies such as solar, biomass, and tidal energies to generate electricity, thus reducing the consumption of dirty energies. The government needs to continue to create awareness in the public of how to use energy efficiently and organise a sustainable development campaign to reduce $CO_2$ emission levels in Indonesia.

Corruption is a serious problem in Indonesia and harms environmental quality. The government must ensure that integrity and professionalism are top priorities for government officials. Those who have the power to approve any projects should be monitored closely by government agencies to avoid any wrongdoings, such as corruption.

Lastly, the Indonesian government should provide various incentives to foreign companies in order to encourage them to use green technology. However, those who harm the environment may need to pay taxes.

This study has its limitations. For example, it uses a limited number of independent variables to explain $CO_2$ emissions in Indonesia. Therefore, future research needs to consider other potential variables affecting $CO_2$ emissions, such as education (Antweiler et al., 2004) and local culture.

## Data availability statement

The raw data supporting the conclusion of this article will be made available by the authors, without undue reservation.

## Author contributions

AR and AP worked together on data collection and statistical analysis, and contributed to the writing of the manuscript. The rest of the authors helped refine each section of the manuscript. All authors have read and agreed to the published version of the manuscript.

## Funding

This research project is a collaboration between two universities: Universiti Teknologi MARA, Malaysia, and Universitas Negeri Semarang, Indonesia, under the Strategic Partnership Research grant. The authors wish to extend their gratitude to Universiti Teknologi MARA (100-RMC5/3/SRPINT(010/2022) and Universitas Negeri Semarang (B/2453/UN37.1.7/KS/2022) for financing this research project.

## Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

## Publisher's note

All claims expressed in this article are solely those of the authors and do not necessarily represent those of their affiliated organizations, or those of the publisher, the editors, and the reviewers. Any product that may be evaluated in this article, or claim that may be made by its manufacturer, is not guaranteed or endorsed by the publisher.

## References

Abdouli, M., and Hammami, S. (2017). Economic growth, FDI inflows and their impact on the environment: An empirical study for the MENA countries. *Qual. Quantity* 51, 121–146. doi:10.1007/s11135-015-0298-6

Adebayo, T. S., and Akinsola, G. D. (2021). Investigating the causal linkage among economic growth, energy consumption and CO2 emissions in Thailand: An application of the wavelet coherence approach. *Int. J. Renew. Energy Dev.* 10 (1), 17–26. doi:10.14710/ijred.2021.32233

Ahmed, F., Ali, I., Kousar, S., and Ahmed, S. (2022). The environmental impact of industrialization and foreign direct investment: Empirical evidence from asia-pacific region. *Environ. Sci. Pollut. Res.* 29, 29778–29792. doi:10.1007/s11356-021-17560-w

Ahmed, K., Rehman, M. U., and Ozturk, I. (2017). What drives carbon dioxide emissions in the long-run? Evidence from selected South Asian countries. *Renew. Sustain. Energy Rev.* 70, 1142–1153. doi:10.1016/j.rser.2016.12.018

Ahmed, Z., Can, M., Sinha, A., Ahmad, M., Alvarado, R., and Rjoub, H. (2022). Investigating the role of economic complexity in sustainable development and environmental sustainability. *Int. J. Sustain. Devel-404 opment World Ecol.* 29 (8), 1–13. doi:10.1080/13504509.2022.2097330

Ahmed, Z., Zhang, B., and Cary, M. (2021). Linking economic globalization, economic growth, financial development, and ecological footprint: Evidence from symmetric and asymmetric ARDL. *Ecol. Indic.* 121, 107060. doi:10.1016/j.ecolind.2020.107060

Akali, G., Erdogan, S., and Sarkodie, S. A. (2021). Do dependence on fossil fuels and corruption spur ecological footprint. *Environ. Impact Assess. Rev.* 90, 106641. doi:10.1016/j.eiar.2021.106641

Alam, M. S. (2022). Is trade, energy consumption and economic growth threat to environmental quality in Bahrain–evidence from VECM and ARDL bound test approach. *Int. J. Emerg. Serv.* 11 (3). ahead-of-print No. ahead-of-print. doi:10.1108/IJES-12-2021-0084

Ali, H. S., Abdul-Rahim, A. S., and Ribadu, M. B. (2017). Urbanization and carbon dioxide emissions in Singapore: Evidence from the ARDL approach. *Environ. Sci. Pollut. Res.* 24, 1967–1974. doi:10.1007/s11356-016-7935-z

Ali, R., Bakhsh, K., and Yasin, M. A. (2019). Impact of urbanization on CO2 emissions in emerging economy: Evidence from Pakistan. *Sustain. Cities Soc.* 48, 101553. doi:10.1016/j.scs.2019.101553

Ansari, M. A., Haider, S., and Khan, N. A. (2019). Does trade openness affects global carbon dioxide emissions: Evidence from the top $CO_2$ emitters. *Manag. Environ. Qual.* 31 (1), 32–53. doi:10.1108/meq-12-2018-0205

Antweiler, W., Copeland, B. R., and Taylor, M. S. (2004). Is free trade good for the environment. *Am. Econ. Rev.* 91 (4), 877–908. doi:10.1257/aer.91.4.877

Atasoy, B. S. (2017). Testing the environmental kuznets curve hypothesis across the U.S.: Evidence from panel mean group estimators. *Renew. Sustain. Energy Rev.* 77, 731–747. doi:10.1016/j.rser.2017.04.050

Aye, G. C., and Edoja, P. E. (2017). Effect of economic growth on CO2 emission in developing countries: Evidence from a dynamic panel threshold model. *Cogent Econ. Finance* 5 (1), 1379239. doi:10.1080/23322039.2017.1379239

Balsalobre-Lorente, D., Gokmenoglu, K. K., Taspinar, N., and Cantos-Cantos, J. M. (2019a). An approach to the pollution haven and pollution halo hypotheses in MINT countries. *Environ. Sci. Pollut. Res.* 26, 23010–23026. doi:10.1007/s11356-019-05446-x

Balsalobre-Lorente, D., Shahbaz, M., Jabbour, C. J. C., and Driha, O. M. (2019b). "The role of energy innovation and corruption in carbon emissions: Evidence based on the EKC hypothesis," in *Energy and environmental strategies in the era of globalization* (Cham, Switzerland: Springer), 271–304.

Behera, P., and Sethi, N. (2022). Nexus between environment regulation, FDI, and green technology innovation in OECD countries. *Environ. Sci. Pollut. Res.* 29, 52940–52953. doi:10.1007/s11356-022-19458-7

Bosah, C. P., Li, S., Ampofo, G. K. M., and Liu, K. (2021). Dynamic nexus between energy consumption, economic growth, and urbanization with carbon emission: Evidence from panel PMG-ARDL estimation. *Environ. Sci. Pollut. Res.* 2843, 61201–61212. doi:10.1007/s11356-021-14943-x

Caglar, A. E . (2020). The importance of renewable energy consumption and FDI inflows in reducing environmental degradation: Bootstrap ARDL bound test in selected 9 countries. *J. Clean. Prod.* 264, 121663. doi:10.1016/j.jclepro.2020.121663

Cao, H., Khan, M. K., Rehman, A., Dagar, V., Oryani, B., and Tanveer, A. (2022). Impact of globalization, institutional quality, economic growth, electricity and renewable energy consumption on carbon dioxide emission in OECD countries. *Environ. Sci. Pollut. Res.* 29 (16), 24191–24202. doi:10.1007/s11356-021-17076-3

Chandran, V. G. R., Sharma, S., and Madhavan, K. (2010). Electricity consumption-growth nexus: The case of Malaysia. *Energy Policy* 38, 606–612. doi:10.1016/j.enpol.2009.10.013

Chishti, M. Z., Ahmed, Z., Murshed, M., Namkambe, H. H., and Ulucak, R. (2021). The asymmetric associations between foreign direct investment inflows, terrorism, CO2 emissions, and economic growth: A tale of two shocks. *Environ. Sci. Pollut. Res.* 28, 69253–69271. doi:10.1007/s11356-021-15188-4

Cole, M. A., and Fredriksson, P. G. (2009). Mismeasuring biological diversity: Response to hoffmann and hoffmann (2008). *Ecol. Econ.* 68 (4), 925–928. doi:10.1016/j.ecolecon.2008.10.015

Danlami, A. H., Aliyu, S., and Danmaraya, I. A. (2019). Energy production, carbon emissions and economic growth in lower-middle income countries. *Int. J. Soc. Econ.* 46 (1), 97–115. doi:10.1108/IJSE-07-2017-0274

Danmaraya, I. A., and Danlami, A. H. (2021). Impact of hydropower consumption, foreign direct investment and manufacturing performance on Co2 emissions in the ASEAN-4 countries. *Int. J. Energy Sect. Manag.* 16 (5), 856–875. doi:10.1108/IJESM-06-2021-0019

Ganda, F. (2020). The influence of corruption on environmental sustainability in the developing economies of Southern Africa. *Heliyon* 6 (7), 043877–e4416. doi:10.1016/j.heliyon.2020.e04387

Gorus, M. S., and Aslan, M. (2019). Impacts of economic indicators on environmental degradation: Evidence from MENA countries. *Renew. Sustain. Energy Rev.* 103, 259–268. doi:10.1016/j.rser.2018.12.042

Habib, S., Abdelmonen, S., and Khaled, M. (2020). The effect of corruption on the environmental quality in african countries: A panel quantile regression analysis. *J. Knowl. Econ.* 11, 788–804. doi:10.1007/s13132-018-0571-8

Hassaballa, H. (2014). Testing for granger causality between energy use and foreign direct investment inflows in developing countries. *Renew. Sustain. Energy Rev.* 31, 417–426. doi:10.1016/j.rser.2013.12.011

Hongqiao, H., Xinjun, W., Ahmad, M., and Zhonghua, L. (2022). Does innovation in environmental technologies curb CO2 emissions? Evidence from advanced time series techniques. *Front. Environ. Sci.* 10, 407. doi:10.3389/FENVS.2022.930521

Hossain, M. S. (2011). Panel estimation for CO2 emissions, energy consumption, economic growth, trade openness and urbanization of newly industrialized countries. *Energy Policy* 39, 6991–6999. doi:10.1016/j.enpol.2011.07.042

Khan, I., Hou, F., and Le, H. P. (2021). The impact of natural resources, energy consumption, and population growth on environmental quality: Fresh evidence from the United States of America. *Sci. Total Environ.* 754, 142222. doi:10.1016/j.scitotenv.2020.142222

Koc, S., and Bulus, G. C. (2020). Testing validity of the EKC hypothesis in South Korea: Role of renewable energy and trade openness. *Environ. Sci. Pollut. Res.* 27 (23), 29043–29054. doi:10.1007/s11356-020-09172-7

Koengkan, M., Losekann, L. D., and Fuinhas, J. A. (2019a). The relationship between economic growth, consumption of energy, and environmental degradation: Renewed evidence from Andean community nations. *Environ. Syst. Decis.* 39 (1), 95–107. doi:10.1007/s10669-018-9698-1

Koshta, N., Bashir, H. A., and Samad, T. A. (2021). Foreign trade, financial development, agriculture, energy consumption and $CO_2$ emission: Testing EKC among emerging economies. *Indian Growth Dev. Rev.* 14 (1), 50–80. doi:10.1108/igdr-10-2019-0117

Lin, B., and Li, Z. (2020). Spatial analysis of mainland cities' carbon emissions of and aroundGuangdong-Hong Kong-Macao greater Bay area. *Sustain. Cities Soc.* 61, 102299. doi:10.1016/j.scs.2020.102299

Mahmood, H., Alkhateeb, T. T. Y., and Furqan, M. (2020). Exports, imports, foreign direct investment and CO2 emissions in North Africa: Spatial analysis. *Energy Rep.* 6, 2403–2409. doi:10.1016/j.egyr.2020.08.038

Munir, K., and Ameer, A. (2019). Nonlinear effect of FDI, economic growth, and industrialization on environmental quality Evidence from Pakistan. *Manag. Environ. Qual. An Int. J.* 31 (1), 223–234. doi:10.1108/MEQ-10-2018-0186

Musah, M., Kong, Y., Mensah, I. A., Antwi, S. K., Osei, A. A., and Donkor, M. (2021). Modelling the connection between energy consumption and carbon emissions in North Africa: Evidence from panel models robust to cross-sectional dependence and slope heterogeneity. *Environ. Dev. Sustain.* 23, 15225–15239. doi:10.1007/s10668-021-01294-3

Nurgazina, Z., Ullah, A., Ali, U., Koondhar, M. A., and Lu, Q. (2021). The impact of economic growth, energy consumption, trade openness, and financial development on carbon emissions: Empirical evidence from Malaysia. *Environ. Sci. Pollut. Res.* 28, 60195–60208. doi:10.1007/s11356-021-14930-2

Panait, M., Janjua, L. R., Apostu, S. A., and Mihăescu, C. (2022). Impact factors to reduce carbon emissions. Evidences from Latin America, *Evidences from Latin America, Kybernetes* [Epub ahead of print]. doi:10.1108/K-05-2022-0712

Pao, H. T., and Tsai, C. M. (2011). Modeling and forecasting the CO2 emissions, energy consumption, and economic growth in Brazil. *Energy* 36, 2450–2458. doi:10.1016/j.energy.2011.01.032

Paramati, S. R., Ummalla, M., and Apergis, N. (2016). The effect of foreign direct investment and stock market growth on clean energy use across a panel of emerging market economies. *Energy Econ.* 56, 29–41. doi:10.1016/j.eneco.2016.02.008

Pata, U. K., and Amit, K. (2021). The influence of hydropower and coal consumption on greenhouse gas emissions: A comparison between China and India. *Water* 13 (10), 1387. doi:10.3390/w13101387

Pata, U. K., and Caglar, A. E. (2021). Investigating the EKC hypothesis with renewable energy consumption, human capital, globalization and trade openness for China: Evidence from augmented ARDL approach with a structural break. *Energy* 216, 119220. doi:10.1016/j.energy.2020.119220

Pata, U. K., Dam, M. M., and Kaya, F. (2022). How effective are renewable energy, tourism, trade openness, and foreign direct investment on CO2 emissions? An EKC analysis for ASEAN countries. *Environ. Sci. Pollut. Res.* doi:10.1007/s11356-022-23160-z

Pata, U. K. (2018). The effect of urbanization and industrialization on carbon emissions in Turkey: Evidence from ARDL bounds testing procedure. *Environ. Sci. Pollut. Res.* 258, 7740–7747. doi:10.1007/s11356-017-1088-6

Pujiati, A., Oktavilia, S., FafuridaWahyuningrum, I. F., and Damayanti, N. (2020). Environmental quality and regional autonomy in Indonesia. *Int. J. Bus. Manag. Sci.* 10 (2), 217–228.

Pujiati, A., Setiaji, K., Purasani, H. N., and Farliana, N. (2019). Integration of environmental economics to build economic behaviors. *E3S Web Conf.* 125, 02009. doi:10.1051/e3sconf/201912502009

Qin, L., Raheem, S., Murshed, M., Miao, X., Khan, Z., and Kirikkaleli, D. (2021). Does financial inclusion limit carbon dioxide emissions? Analysing the role of globalization and renewable electricity output. *Sustain. Dev.* 29, 1138–1154. doi:10.1002/sd.2208

Rafindadi, A. A., Muye, I. M., and Kaita, R. A. (2018). The effects of FDI and energy consumption on environmental pollution in predominantly resource-based economies of the GCC. *Sustain. Energy Technol. Assess.* 25, 126–137. doi:10.1016/j.seta.2017.12.008

Rahman, M. M. (2020). The dynamic nexus of energy consumption, international trade and economic growth in brics and asean countries: A panel causality test. *Int. J. Energy Sect. Manag.* 14 (6), 1177–1203. doi:10.1016/j.energy.2021.120679

Rehman, A., Ma, H., Ozturk, I., Murshed, M., and Dagar, V. (2021a). The dynamic impacts of CO2 emissions from different sources on Pakistan's economic progress: A roadmap to sustainable development. *Environ. Dev. Sustain.* 23 (12), 17857–17880. doi:10.1007/s10668-021-01418-9

Ridzuan, A. R., Ismail, N. A., and Che Hamat, A. F. (2018). Foreign direct investment and trade openness: Do they lead to sustainable development in Malaysia? *J. Sustain. Sci. Manag.* 4, 79–97.

Ridzuan, A. R., Sapuan, N. M., Abdul Rahman, N. H., Borhan, H., and Othman, A. (2019). The impact of corruption on environmental quality in the developing countries of

ASEAN–3: The application of the bound test. *Int. J. Energy Econ. Policy* 9 (6), 469–478. doi:10.32479/ijeep.8135

Ridzuan, A. R., Shaari, M. S., Rosli, A., Md Jamil, A. R., SiswantiniLestari, A., et al. (2021). The nexus between economic growth and natural resource abundance in selected ASEAN countries before pandemic Covid-19. *Int. J. Energy Econ. Policy* 11 (2), 281–292. doi:10.32479/ijeep.10615

Sehrawat, M., Giri, A. K., and Mohapatra, G. (2015). The impact of financial development, economic growth and energy consumption on environmental degradation: Evidence from India. *Manag. Environ. Qual. An Int. J.* 26 (5), 666–682. doi:10.1108/meq-05-2014-0063

Sekrafi, H., and Sghaier, A. (2017). The effect of corruption on carbon dioxide emissions and energy consumption in Tunisia. *PSU Res. Rev.* 2 (1), 81–95. doi:10.1108/prr-11-2016-0008

Shahbaz, M., Tiwari, A. K., and Nasir, M. A. (2013). The effects of financial development, economic growth, coal consumption and trade openness on CO2 emissions in South Africa. *Energy Policy* 61, 1452–1459. doi:10.1016/j.enpol.2013.07.006

Sugiawan, Y., and Managi, S. (2016). The environmental Kuznets curve in Indonesia: Exploring the potential of renewable energy. *Energy Policy* 98, 187–198. doi:10.1016/j.enpol.2016.08.029

Terzi, H., and Pata, U. K. (2019). Is the pollution haven hypothesis (PHH) valid for Turkey? *Panoeconomicus* 67 (1), 93–109. doi:10.2298/PAN161229016T

Usman, O. (2022). Modelling the economic and social issues related to environmental quality in Nigeria: The role of economic growth and internal conflict. *Environ. Sci. Pollut. Res.* 29, 39209–39227. doi:10.1007/s11356-021-18157-z

Wang, S., Zhao, D., and Chen, H. (2020). Government corruption, resource misallocation, and ecological efficiency. *Energy Econ.* 85, 104573. doi:10.1016/j.eneco.2019.104573

Wasti, S. K. A., and Zaidi, S. W. (2020). An empirical investigation between CO2 emission, energy consumption, trade liberalization and economic growth: A case of Kuwait. *J. Build. Eng.* 28, 101104–104. doi:10.1016/j.jobe.2019.101104

Yilanci, V., and Pata, U. K. (2020). Investigating the EKC hypothesis for China: The role of economic complexity on ecological footprint. *Environ. Sci. Pollut. Res.* 27 (26), 32683–32694. doi:10.1007/s11356-020-09434-4

Zambrano-Monserrate, M. A., Silva-Zambrano, C. A., Davalos-Penafiel, J. L., Zambrano-Monserrate, A., and Ruano, M. A. (2018). Testing environmental Kuznets curve hypothesis in Peru: The role of renewable electricity, petroleum and dry natural gas. *Renew. Sustain. Energy Rev.* 82, 4170–4178. doi:10.1016/j.rser.2017.11.005