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Jurnal

FRONTIERS IN ENVIRONMENTAL SCIENCE, SECTION ENVIRONMENTAL ECONOMICS AND MANAGEMENT

Judul

THE DETRIMENTAL EFFECTS OF CORRUPTION, FOREIGN INVESTMENT AND DIRTY ENERGY ONENVIRONMENTAL QUALITY: FRESH PERSPECTIVE FROM INDONESIA

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Journal Scope: Environmental Economics and Management

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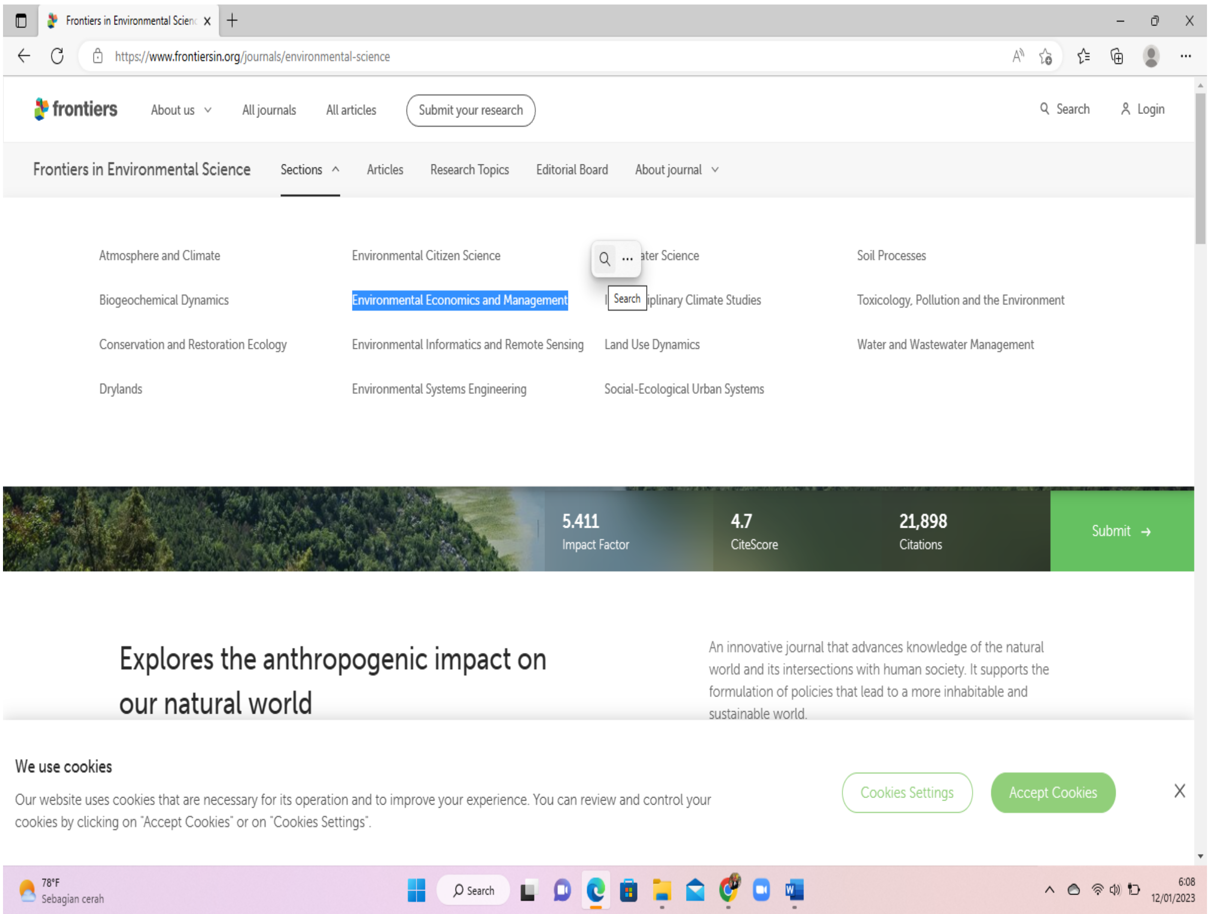

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The Detrimental Effects of Dirty Energy, Foreign Investment and Corruption, on Environmental Quality: New Evidence from Indonesia

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Original Research, Front. Environ. Sci. - Environmental Economics and Management

Received on: 19 Oct 2022, **Edited by:** Mobeen Ur Rehman

Manuscript ID: 1074172

Keywords: CO2 emissions1, Foreign direct investment2, corruption3, Energy use4, Environmental quality5

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	Reviewer 2 posted new comments.
26 Nov 2022	Review of Review Editor 1 finalized.
25 Nov 2022	You posted new comments.
	Associate Editor Mobeen Ur Rehman reactivated the review of Review Editor 2.
	Associate Editor Mobeen Ur Rehman reactivated the review of Review Editor 1.
23 Nov 2022	Review of Review Editor 1 finalized.
	Corresponding Author Abdul Rahim Ridzuan re-submitted manuscript.
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17 Nov 2022	Interactive review forum activated.
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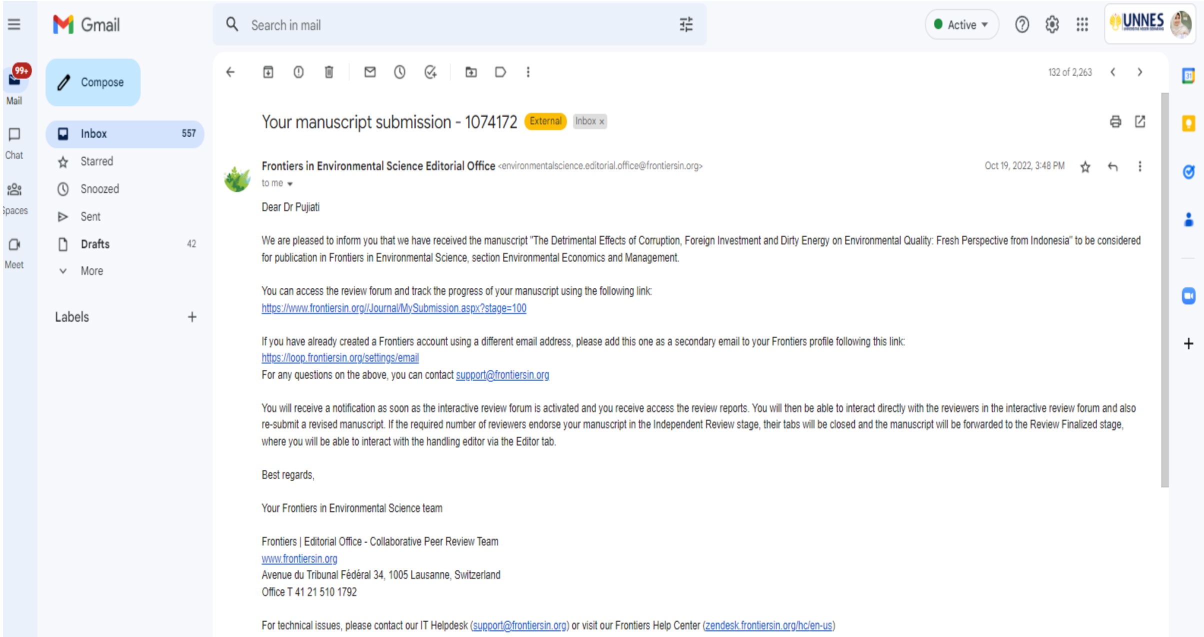

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The Detrimental Effects of Corruption, Foreign Investment and Dirty Energy on Environmental Quality: Fresh Perspective from Indonesia

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Keywords: CO2 emissions[1], Foreign direct investment[2], Corruption[3], Energy use[4], Environmental quality[5].

Abstract

The alarming trend of CO2 emissions in Indonesia merits a reinvestigation into the determinants in a bid to conserve the environment. This study aims to evaluate the Environmental Kuznets Curve (EKC) hypothesis and examine the relationship between economic growth (GDP), corruption (COR), energy use (ENY), foreign direct investment (FDI), urbanization (URB) and CO2 emissions in Indonesia. The autoregressive distributed lag (ARDL) approach is employed to analyze data, for 36 years from 1984 to 2020, on GDP, corruption, energy use, FDI, and urbanization on CO2 emissions. The results reveal that economic growth and corruption contribute to greater environmental degradation in the short run, while FDI and urbanization do not. In the long run, corruption and energy use can positively affect environmental degradation, but FDI can reduce environmental degradation in Indonesia. These findings are indispensable for policy formulation in Indonesia. Public health remains important welfare agenda for the nation, and it can also be done through assessment of the country's environmental quality.

1 Introduction

In the last few decades, the development process in developing countries has progressed very rapidly. They have carried out a development transformation from agriculture to industrialization, which has boosted economic growth and improved people's living standards. The change of power from the old order regime to the new order has changed Indonesia's economic policy. In the 80s, Indonesia sought to expand economic growth and encourage energy use, rapid urbanization, and foreign direct investment. Figure 1 shows Indonesia's Gross Domestic Product (per capita 2005) increased from 1984-2020. The value of GDP per capita in 1984 was 1816 US Dollars, and in 2020 it was 3,757 US Dollars. This condition shows a significant increase in the prosperity and welfare of the people. But, GDP from the industrial and manufacturing sectors already decreases the quality of the environment in Indonesia (Pujiati et al., 2020).

[FIGURE 1]

However, the development strategies of developing countries in accelerating economic performance supported by population growth and the improvement of urban communities have encouraged environmental pollution (Sehrawa et al, 2015). The impact of unmoderated development and technological progress has pushed us to face sustainable development challenges, namely environmental degradation, climate change, and exploitation of natural resources (Kostha, 2021). Rahman (2020) states that the expansion of economic growth requires additional production from industry, and the additional energy consumption is unavoidable, which drives carbon emissions. Alam (2022) argues that in developing countries, the requirements for increased economic growth have undermined the quality of the environment and have had a lasting impact on development and industrialization. Although the Government of Indonesia has encouraged sustainable development, there has been an increase in CO2 emissions in Indonesia. Figure 2 shows an increase in CO2 emissions of 2.09% from 1984 to 2020. The value of CO2 emissions in 1984 was 0.7 metrics per capita and reached 2.16 metrics per capita in 2020. Factors driving CO2 emissions in developing countries include population growth and urbanization (Ansari et al., 2019). Many people are more desirable moving to cities because of the development of urban areas with all their attractiveness (Pujiati et al., 2019).

[FIGURE 2]

Danmaraya & Danlami (2021) state that the driving factor for CO2 emissions is a 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 economic patterns. The effect of scale is that FDI has a negative impact on the environment by increasing the size of the country's economy. Meanwhile, the engineering effect states that foreign companies can adopt more environmentally friendly technologies and improve the environment by reducing emissions. Munir & Ameer (2019) stated that FDI replaces domestic companies and introduces inappropriate technology, which is the primary source of pollution. Figure 3 shows the development of FDI in Indonesia from 1984-2020, which fluctuated yearly.

[FIGURE 3]

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 (Lameira, 2012). Community supervision is essential so the government can avoid unethical and irresponsible actions. Corruption is a global problem with power that can affect all countries and all sectors of activity (Sekrafi & Sghaier, 2017). High levels of corruption indicate lousy governance. Data on corruption in a country comes from the Corruption Perception Index (CPI) issued by Transparency International. Indonesia's CPI value in 1984 was 1.00 and increased to 3.00 in 2020, as shown in Figure 4. This condition shows a tendency to increase corrupt behavior in the bureaucracy in Indonesia. Ganda (2022) found that corrupt behavior using two indices, namely the corruption index and corruption rankings, has worsened environmental sustainability in 16 countries in southern Africa. Cole & Fredrikson (2009) found that countries with weak environmental institutions will attract more polluting industries that encourage environmental damage.

[FIGURE 4]

This paper investigates the impact of economic growth, corruption, energy use, foreign direct investment, and urbanization growth on environmental quality in Indonesia from 1984-2020. 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 conclusion and policy recommendations.

2 Literature review

On a theoretical level, the model by Antweiller et al. (2004) 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). The EKC hypothesis has been used by a large number of researchers to investigate the relationship between economic growth and environmental quality (Yilanci and Pata, 2020). The theory's validity has been demonstrated in a number of 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). Some studies, on the other hand, have been unable to establish a link between economic growth and environmental degradation. For example, Zambrano-Monserrate et al. (2018) investigate the Peruvian nexus and discover that the findings do not support the EKC hypothesis. Another study on South Korea by Koc and Bulus (2020) finds evidence of an N-shaped relationship between economic growth and environmental degradation, which invalidates the EKC theory.

A number of studies have been conducted to investigate the relationship between energy consumption and environmental degradation, particularly CO2 emissions (Khan, Hou and Le, 2021). Wasti and Zaidi (2020) find a link between energy consumption and environmental degradation in Kuwait. Adebayo and Akinsola (2021) reveal a bidirectional link between environmental degradation and energy consumption in Thailand using the wavelet coherence method, classical Granger, and Toda-Yamamoto causality approaches. Besides that, Ahmed et al. (2017), Aye and Edoja (2017), and Musah et al. (2021) identify energy consumption as a major contributor to CO2 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 panel data from 15 countries on energy consumption, economic growth, urbanisation, and carbon emissions. The findings indicate that 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) investigated the relationship between urbanisation and carbon emissions in Singapore and Turkey, respectively, but their findings differed; urbanisation in Singapore inhibits carbon emissions, whereas urbanisation in Turkey promotes carbon emissions. With Japanese research subjects, Ahmed et al. (2021) examined the impact of globalisation, economic growth, and financial development on carbon footprint. The findings revealed that increased energy consumption and financial development would substantially increase carbon footprint, while the relationship between economy and carbon footprint exhibited an inverted U shape, confirming the validity of EKC in Japan.

The existing literature on the relationship between corruption and environmental sustainability is active (Usman, 2022; Ganda, 2020; Wang, Zhao and Chen, 2020). According to popular belief, corruption can both 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 environmental quality in Nigeria. While economic growth exacerbated environmental degradation in Nigeria, corruption and internal conflict mitigated environmental degradation by reducing investment and growth. The authors of Wang, Zhao and Chen (2020) used system GMM on provincial panel data in China's industry from 2005 to 2015 to establish that corruption influences CO2 emissions through environmental policy distortion and lower monitoring levels. Furthermore, Habib, Abdelmonen and Khaled (2020) investigated how corruption affects CO2 emissions and economic growth in Africa using a panel quantile regression method. The findings were as follows: (i) a higher level of corruption in Africa; (ii) corruption is negatively related to CO2 emissions in lower emitting countries; (iii) corruption is not a significant enough factor in higher emitting countries to explain changes in CO2 emissions; and (iv) corruption is positively affected by CO2 emissions. Because the positive effect outweighs the negative effect, the overall effect of corruption is positive.

Regarding the relationship between FDI and CO2 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 CO2 emissions and contributes to environmental degradation. This assertion was supported by the study of Abdouli and Hammami (2017), which found that FDI has a positive impact on 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, the authors of Behera and Sethi (2022) discovered that environmental regulation has a significant effect on green technology innovation and that FDI causes green technology innovation to decrease.

[TABLE 1]

Methodology

The general functional form of the environmental quality model for Indonesia is derived as follows:

$$CO2_t = f(GDP_t, COR_t, ENY_t, FDI_t, UBG_t) \ldots (1.0)$$

where

CO2t represents environmental quality,
GDPt represents economic growth,
CORt represents corruption,
ENYt represents energy used,

FDIt represent foreign direct investments inflows,
UBGt represents urbanization growth

The variables in equation 2 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. (2012), the log version of the tested variables can produce a consistent and reliable estimation. The log version of the model derived from Equation 1.0 can be seen as follows:

$$LNCO2_t = \delta_0 + \alpha_1 LNGDP_t + \beta_2 LNCOR_t + \sigma_3 LNENY_t + \phi_4 LNFDI_t + \tau_7 LNUBG_t + \mu_t \ldots(2.0)$$

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 the past studies conducted for Malaysia, such as Ridzuan et al. (2018), Ridzuan et al. (2019), and Raihan and Tuspekova (2022). Next, (LNCOR) is expected to have either positive or negative relationship with LNCO2, depending on the government rules and integrity when managing their country. Next, 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 outcomes can be seen from the 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 also proved by Rafindadi et al. (2018) and Balsalobre-Lorente et al. (2019). The pollution Haven Hypothesis is a situation where foreign investors decide to invest more money into the 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 host countries. Similar to LNGDP, energy used also exhibits a positive relationship with LNCO2. Higher energy generated for the combustion of fossil fuels will lead to a higher release of carbon emissions in the country. With regard to urbanization, some studies suggest that the increased population caused by urbanization triggers intensive urban economic activity, which leads to increased demand for energy and increased carbon emissions (Ali et al. 2019). However, some studies suggest that urbanization brings about economies of scale and improves public infrastructure, thereby reducing carbon emissions (Lin and Li, 2020). No consistent conclusions have been reached.

The ARDL model considering each of the variables in turn as the dependent variable based on the Unrestricted Error Correction Model (UECM) are stated below:

$$\Delta LNCO2_t = \beta_1 + \theta_0 LNCO2_{t-1} + \theta_1 LNGDP_{t-1} + \theta_2 LNCOR_{t-1} + \theta_3 LNENY_{t-1} + \theta_4 LNFDI_{t-1} + \theta_5 LNUBG_{t-1} +$$
$$+ \sum_{i=1}^{a} \beta_i \Delta LNCO2_{t-i} + \sum_{i=0}^{b} \gamma_i \Delta LNGDP_{t-i} + \sum_{i=0}^{c} \delta_i \Delta LNCOR_{t-i} + \sum_{i=0}^{d} \lambda_i \Delta LNENY_{t-i} + \sum_{i=0}^{e} \vartheta_i \Delta LNFDI_{t-i} + \sum_{i=0}^{f} \psi_i \Delta LNUBG_{t-i} + \upsilon_t \ldots(3.0)$$

$$\Delta LNGDP_t = \beta_2 + \theta_0 LNCO2_{t-1} + \theta_1 LNGDP_{t-1} + \theta_2 LNCOR_{t-1} + \theta_3 LNENY_{t-1} + \theta_4 LNFDI_{t-1} + \theta_5 LNUBG_{t-1} +$$
$$+ \sum_{i=1}^{a} \beta_i \Delta LNGDP_{t-i} + \sum_{i=0}^{b} \gamma_i \Delta LNCO2_{t-i} + \sum_{i=0}^{c} \delta_i \Delta LNCOR_{t-i} + \sum_{i=0}^{d} \lambda_i \Delta LNENY_{t-i} + \sum_{i=0}^{e} \vartheta_i \Delta LNFDI_{t-i} + \sum_{i=0}^{f} \psi_i \Delta LNUBG_{t-i} + \upsilon_t \ldots(4.0)$$

$$\Delta LNCOR_t = \beta_3 + \theta_0 LNCO2_{t-1} + \theta_1 LNGDP_{t-1} + \theta_2 LNCOR_{t-1} + \theta_3 LNENY_{t-1} + \theta_4 LNFDI_{t-1} + \theta_5 LNUBG_{t-1} +$$
$$+ \sum_{i=1}^{a} \beta_i \Delta LNCOR_{t-i} + \sum_{i=0}^{b} \gamma_i \Delta LNGDP_{t-i} + \sum_{i=0}^{c} \delta_i \Delta LNCO2_{t-i} + \sum_{i=0}^{d} \lambda_i \Delta LNENY_{t-i} + \sum_{i=0}^{e} \vartheta_i \Delta LNFDI_{t-i} + \sum_{i=0}^{f} \psi_i \Delta LNUBG_{t-i} + \upsilon_t \ldots(5.0)$$

$$\Delta LNENY_t = \beta_4 + \theta_0 LNCO2_{t-1} + \theta_1 LNGDP_{t-1} + \theta_2 LNCOR_{t-1} + \theta_3 LNENY_{t-1} + \theta_4 LNFDI_{t-1} + \theta_5 LNUBG_{t-1} +$$
$$+ \sum_{i=1}^{a} \beta_i \Delta LNENY_{t-i} + \sum_{i=0}^{b} \gamma_i \Delta LNGDP_{t-i} + \sum_{i=0}^{c} \delta_i \Delta LNCOR_{t-i} + \sum_{i=0}^{d} \lambda_i \Delta LNCO2_{t-i} + \sum_{i=0}^{e} \vartheta_i \Delta LNFDI_{t-i} + \sum_{i=0}^{f} \psi_i \Delta LNUBG_{t-i} + \upsilon_t \ldots(6.0)$$

$$\Delta LNUBG_t = \beta_5 + \theta_0 LNCO2_{t-1} + \theta_1 LNGDP_{t-1} + \theta_2 LNCOR_{t-1} + \theta_3 LNENY_{t-1} + \theta_4 LNFDI_{t-1} + \theta_5 LNUBG_{t-1} +$$
$$+\sum_{i=1}^{a}\beta_i \Delta LNUBG_{t-i} + \sum_{i=0}^{b}\gamma_i \Delta LNGDP_{t-i} + \sum_{i=0}^{c}\delta_i \Delta LNCOR_{t-i} + \sum_{i=0}^{d}\lambda_i \Delta LNENY_{t-i} + \sum_{i=0}^{e}\vartheta_i \Delta LNFDI_{t-i} + \sum_{i=0}^{f}\psi_i \Delta LNCO2_{t-i} + \upsilon_t ...(7.0)$$

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 Equation (4.0) above 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 short-run effects are captured by the coefficients of the first differenced variables. The null of no co-integration in the long-run relationship is defined by:

$H0$: $\theta 0=\theta 1=\theta 2=\theta 3=\theta 4=\theta 5=0$ (there is no long-run relationship),

is tested against the alternative of

$H1$: $\theta 0\neq\theta 1\neq\theta 2\neq \theta 3\neq\theta 4\neq\theta 5\neq 0$ (there is 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 aim to test the Environmental Kuznets Curve (EKC) hypothesis for Indonesia, where previous literature, using panel data analysis, has presented mixed and ambiguous evidence for each nation (Narayanan & Narayanan, 2010; Hossain, 2012). To get around some of the issues with panel data analysis, we used time series analysis in our study. Furthermore, to deliver reliable results, country-specific analyses like this study are required (Chandran, Sharma & Madhavan, 2010). In addition, our study strongly emphasises the causal links between FDI and CO2 emissions, which gives us less insight into the pollution haven theory. According to previous literature, FDI may increase global CO2 emissions if environmental regulations are loosened in developing nations (Pao & Tsai, 2011).

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

[TABLE 2]

Result and Discussion

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

[TABLE 3]

In examining the long-run relationship between CO2 and its determinants, we proceed to the bounds testing approach for all possible model and the results are reported in Table 4. The computed F-statistics for CO2, GDP, COR, and FDI equation suggests rejection of the null hypothesis of no cointegration. The F statistic from this model are significant between 1 to 10% significant level. However, the null hypothesis is not rejected for other equations. Based on the main model, we able to proceed to the long run and short run elasticities and the following analysis will be solely on this model.

[TABLE 4]

Before proceeding to the main outcomes, we need to ensure that the model we run have passed all diagnostic tests. Among diagnostic tests that we performed are serial correlation, function form, normality, heteroscedasticity, and stability model consist of CUSUM and CUSUM sq tests. Based on Table 5, it is confirmed that the carbon emissions model that we focus on this study have passed all the diagnostic as shown in Table 4 below. The probability value for the first four tests is more than 10% significance level and thus confirming that the model are free from serial correlation problem, the model is functioning well, the model is normally distributed and there is no heteroscedasticity problem.

[TABLE 5]

We also performed CUSUM and CUSUM sq to ensure the stability of the model. Based on Figure 5, the blue line is in between the two red dotted line thus confirming that the model in a good shaped.

[FIGURE 5]

Table 6 presents the main analysis based on short run and long run elasticities. Begin with the the short run outcomes we found out that both LNGDP and LNCOR have a positive association with environmental degradation in Indonesia. Statically, 1% increases in LNGDP and LNCOR lead to 1.28% and 0.01% increased in carbon emissions releases. Rapid development in the country causes pollution more as compared to governance. Meanwhile, other variables such as LNENY, LNFDI and LNRUB 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 appear to be negative and statistically significant. Based on the ECT value, the speed of adjustment was obtained by Indonesia is -0.731. For instance, this value indicated that more than 73% of adjustments were completed within less than a year and all the variables are converges 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 CO2 emissions is positive and it is significant at 10 per cent level. Keeping other things same, a 1 per cent increase in economic growth raises CO2 emissions by 0.31 per cent. This outcome is similar to the previous research performed by Shahbaz et al. (2013), Sugiawan and Managi (2016) Our empirical exercise indicates that economic growth is the second largest contributor to CO2 emissions in case of Indonesia. Our empirical exercise indicates that energy use (LNENY) is the largest contributor to carbon emission in case of Indonesia. Assuming other things remain same, a 1% increase in LNEY lead to 0.64% increase in carbon emissions. Indonesia economy is still heavily relay on coal as cheaper sources of energy for the purpose of economic development; however, it has degraded the climate quality (Ahmed et al. 2022; Hongqiao et al. 2022; Ridzuan et al. 2021). Systemic corruption that occurs in Indonesia has a long-term worsening effect on environmental degradation. Statistically, a 1% increase in LNCOR lead to an increase of 0.09% increase in carbon emission. This finding support previous findings by Akalin et al. 2021 where corruption has a positive effect on environmental pollution. The rise of corruption may lead to the an extension of economic activities by short-circuiting the bureaucratic process which triggers more resource utilization—which in turn 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., 2019). The corruption level indeed could has hindered the country progress towards achieving environmental sustainability. The only favoured outcome from this model is LNFDI. The result revealed that LNFDI have a negative relationship with LNCO2. Technically, 1 percent increase in LNFDI decreases LNCO2 emissions by 0.03%. This outcome validates the Halo Effect Hypothesis where higher level of foreign investment that focus on green and clean technology help the nation to curb the amount of emissions releases from the industries. This result is in line with the studies performed by Rafindadi et al. (2018).

[TABLE 6]

Conclusion and Policy Recommendations

This study aims to test the Environmental Kuznets Curve (EKC) hypothesis and analyze the dynamics of the relationship between GDP, corruption, energy use, FDI, and urbanization on CO^2 emissions in Indonesia. This study uses an autoregressive distributed lag (ARDL) to analyze the dynamics of short-term and long-term effects of GDP, corruption, energy use, FDI, and urbanization on CO^2 emissions. This study finds that in the short term, 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 urbanization have no effect on CO^2 emissions. In the long term, the variables that affect CO^2 emissions are GDP, corruption, energy use, and FDI. Urbanization in the long term also does not affect CO^2 emissions. GDP, corruption, and energy use have a positive effect, while FDI has a negative effect on CO^2 emissions in Indonesia.

The results of the short and long-term analysis prove the presence of EKC hypothesis. The level of development that produces GDP has a positive effect on CO^2 emissions. The greater GDP, the greater the resulting $C0^2$ emissions. GDP, corruption, and energy used have a dynamic short-term and long-term relationship with a high speed of adjustment to balance up to 73% per year. This condition shows that GDP, corruption, energy used, and FDI in macroeconomic policymaking must always pay attention to their impact on reducing CO^2 emissions. This research reveals that the energy used and GDP play an essential role in reducing the level of CO^2 emissions seen from the large coefficient value in the long term. In this case, the government must provide strict regulations regarding the type of energy used in the production process to reduce CO^2 emissions. In addition, the government needs to continue to increase appeals to the public for efficient use of energy and campaign for a sustainable energy crisis through formal and non-formal education and training programs that can help reduce CO^2 emission levels in Indonesia. The limitation of this study is that it uses more economic variables to explain CO^2 emissions in Indonesia. Therefore, future research needs to consider adding other variables estimated to affect CO^2 emissions, such as education and local culture. Education and local culture greatly influence people's behavior in increasing environmental insight.

Author contributions

Ridzuan, A.R and Pujiati, A work together on data collection and statistical analysis, and contributed to the writing of the manuscript. The rest authors help to refine each section of the paper. All authors have read and agree to the published version of the manuscript.

Conflict of interest

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

Funding

We wish to extend our gratitude to Universiti Teknologi MARA (100-RMC5/3/SRPINT(010/2022) and Universitas Negeri Malang (B/2453/UN37.1.7/KS/2022) for financing this research project.

Acknowledgments

This research project is a collaboration between two universities: Universiti Teknologi MARA, Malaysia and Universitas Negeri Semarang, Indonesia under Strategic Partnership Research grant.

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TABLE 1: Summary of Literature Review

Author	Findings
Zambrano-Monserrate et al. (2018)	Investigate the Peruvian nexus and discover that the findings do not support the EKC hypothesis.
Koc and Bulus (2020)	Finds evidence of an N-shaped relationship between economic growth and environmental degradation, which invalidates the EKC theory.
Wasti and Zaidi (2020)	Finds a link between energy consumption and environmental degradation in Kuwait.
Adebayo and Akinsola (2021)	Reveal 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)	Identify energy consumption as a major contributor to CO_2 emissions in five South Asian countries, 31 emerging economies, and North Africa, respectively.
Bosah et al. (2021)	Examined panel data from 15 countries on energy consumption, economic growth, urbanisation, and carbon emissions. The findings indicate that 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)	Investigated the relationship between urbanisation and carbon emissions in Singapore and Turkey, respectively, but their findings differed; urbanisation in Singapore inhibits carbon emissions, whereas urbanisation in Turkey promotes carbon emissions.
Ahmed et al. (2021)	Examined the impact of globalisation, economic growth, and financial development on carbon footprint. The findings revealed that increased energy consumption and financial development would substantially increase carbon footprint, while the relationship between economy and carbon footprint exhibited an inverted U shape, 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)	Used 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 distortion and lower monitoring levels.
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: (i) a higher level of corruption in Africa; (ii) corruption is negatively related to CO_2 emissions in lower emitting countries; (iii) corruption is not a significant enough factor in higher emitting countries to explain changes in CO_2 emissions; and (iv) 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)	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 CO2 emissions and contributes to environmental degradation. 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 CO2 emissions and contributes to environmental degradation.
Abdouli and Hammami (2017)	Found that FDI has a positive impact on 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 has a significant effect on green technology innovation and that FDI causes green technology innovation to decrease.

TABLE 2: Sources of data

Variables	Description	Sources
LNCO2	CO2 emissions (metric tons per capita)	WDI
LNGDP	GDP per capita (constant 2015 US$)	WDI
LNCOR	Corruption Perception 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 Indicator 2022

TABLE 3: Testing ADF and PP Unit Root

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	-0.434 (0)	-2.426 (1)	-0.434 (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)
LNRUB	-0.233 (0)	-2.246 (0)	-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)***
LNRUB	-5.917 (0)***	-5.839 (0)***	-5.923 (3)***	-5.842 (3)***

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

TABLE 4: Detecting the presence of long run cointegration based on F stat.

Model	Max Lag	Lag order	F statistics	Result
LNCO2 = f(LNGDP,LNCOR, LNENY, LNFDI, LNUBG)	(4,4)	(1,1,0,1,0,0)	5.929***	Cointegration
LNGDP = f(LNCO2,LNCOR, LNENY, LNFDI, LNUBG)	(4,4)	(1,3,0,1,1,0)	3.534*	Cointegration
LNCOR = f(LNCO2,LNGDP, LNENY, LNFDI, LNUBG)	(4,4)	(4,3,4,4,4,4)	3.854**	Cointegration
LNENY = f(LNCO2,LNGDP, LNCOR, LNFDI, LNUBG)	(4,4)	(1,0,0,0,0,0)	1.400	No cointegration
LNFDI = f(LNCO2,LNGDP, LNCOR, LNENY, LNUBG)	(4,4)	(4,3,4,4,4,4)	5.724***	Cointegration
LNUBG = f(LNCO2,LNGDP, LNCOR, LNENY, LNFDI)	(2,2)	(1,0,0,2,0,0)	2.833	No cointegration
Critical Values for F stat		Lower I(0)	Upper (1)	
10%		2.26	3.35	
5%		2.62	3.79	
1%		3.41	4.68	

Note: 1. k is a number of variables and it is equivalent to 5. 2. *, **, and *** represent 10%, 5% and 1% level of significance, respectively. Estimation is based on 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 [0.703]	1.241 [0.275]	1.249 [0.535]	0.878 [0.547]

Note. 1. ** represent 5% significant levels. 2. The diagnostic test 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.

TABLE 6: Short run and Long run Elasticities

Short run Elasticities		Long run Elasticities	
Variables	Coefficient	Variables	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(LNRUB)	-0.170	LNRUB	-0.232
CointEq(-1)	-0.731***	C	-6.039***

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

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EVALUATION
Please list your revision requests for the authors and provide your detailed comments, including highlighting limitations and strengths of the study and evaluating the validity of the methods, results, and data interpretation. If you have additional comments based on Q2 and Q3 you can add them as well.
Q1) 1816 US Dollars, and in 2020 it was 3,757 US
39 Dollars. One has a comma, one does not. Why? Provide integrity in your work.
Q2) The introductory part of the study is like a short review of the literature. The introduction part needs to be developed with theoretical foundations. The relationship between FDI and CO_2 emissions can be explained by the PHH hypothesis. The authors do not refer to this.
Q3) In the introduction, there is no information about the origin of the study and its contribution to the literature. Why is this study being done?
Q4) What is the gap in the literature? In the literature section, do not specify only what some studies do. Highlight the research gap in the literature.
Q5) Benefit from further studies on the FDI-CO_2 relationship in the literature.
http://dx.doi.org/10.2298/PAN161229016T; https://doi.org/10.1007/s11356-022-23160-z; https://doi.org/10.3390/w13101387
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No
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No
c. Are the statistical methods valid and correctly applied? (e.g. sample size, choice of test)
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1) Please rewrite an abstract and check the connection between sentences.
2) some of the paragraphs in chapter 1 do not have a connection, please improve them.
3) Please explain the related issues of environmental quality and corruption in Indonesia (before the graph of
4) lack of novelty - should add
5) How the model specification is derived? Is it derived from the IPAT model or the Kuznets curve model? Please check.
6) Please check the references. Some references are missing, and some have a mistake in name and years.

Check List
a. Is the quality of the figures and tables satisfactory?
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b. Does the reference list cover the relevant literature adequately and in an unbiased manner?
Yes
c. Are the statistical methods valid and correctly applied? (e.g. sample size, choice of test)
Yes
d. Is a statistician required to evaluate this study?
No
e. Are the methods sufficiently documented to allow replication studies?
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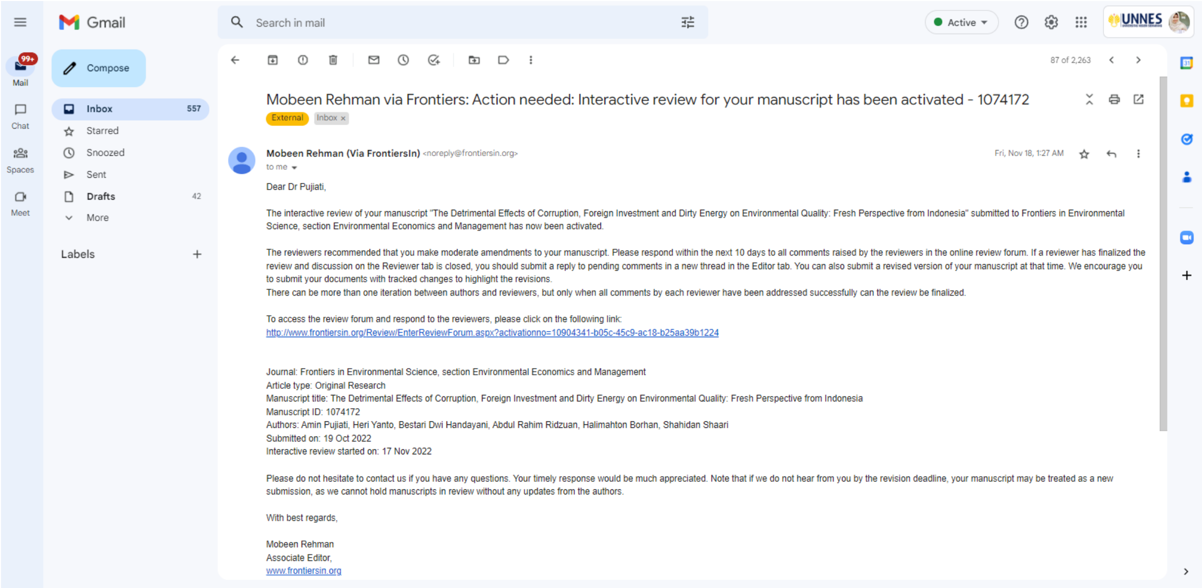

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Article type: Original Research
Manuscript title: The Detrimental Effects of Corruption, Foreign Investment and Dirty Energy on Environmental Quality: Fresh Perspective from Indonesia
Manuscript ID: 1074172
Authors: Amin Pujiati, Heri Yanto, Bestari Dwi Handayani, Abdul Rahim Ridzuan, Halimahton Borhan, Shahidan Shaari
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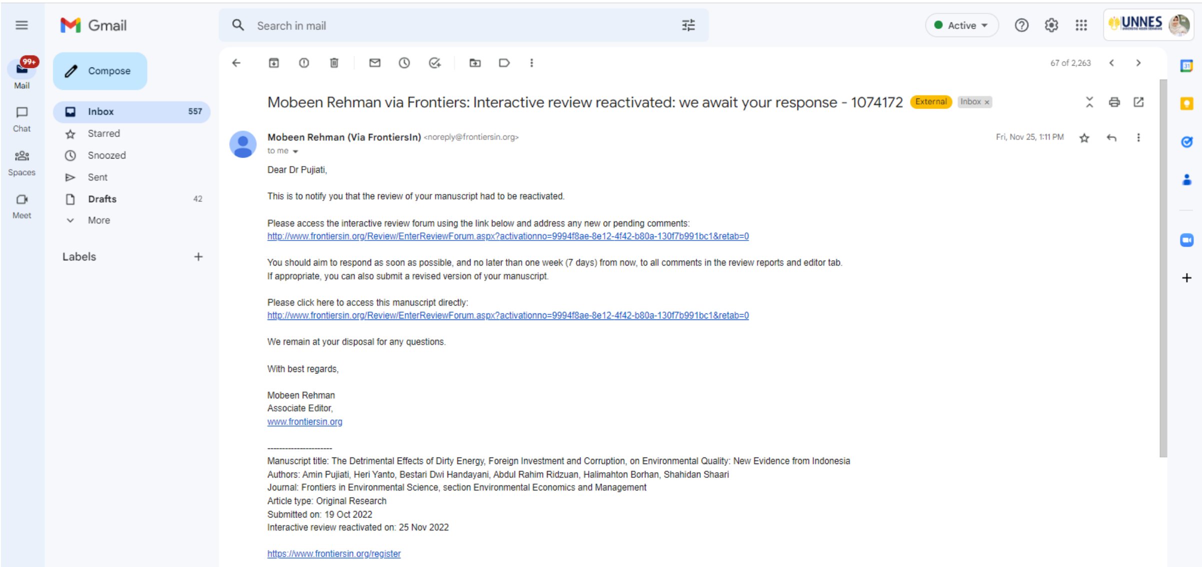

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The Detrimental Effects of Dirty Energy, Foreign Investment and Corruption, on Environmental Quality: New Evidence from Indonesia

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Keywords: CO_2 emissions[1], Foreign direct investment[2], Corruption[3], Energy use[4], Environmental quality[5].

Abstract

The alarming trend of CO_2 emissions in Indonesia merits a reinvestigation into the determinants in a bid to conserve the environment. In literature, in Indonesia, three potential determinants, energy, FDI 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 employed 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 FDI does not. However, in the long run, corruption and energy use can positively affect environmental degradation, but FDI can reduce environmental degradation in Indonesia. This study also found two other factors, namely economic growth and urbanisation, that 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.

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 changed Indonesia's economic policy. Since the 1980s, Indonesia has sought to boost economic growth, leading to higher energy use and rapid urbanisation. Besides, the country has successfully attracted higher foreign direct investment through numerous government incentives and tax reforms. Figure 1 shows the growth of Indonesia's Gross Domestic Product (per capita 2005) from 1984-2020. 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).

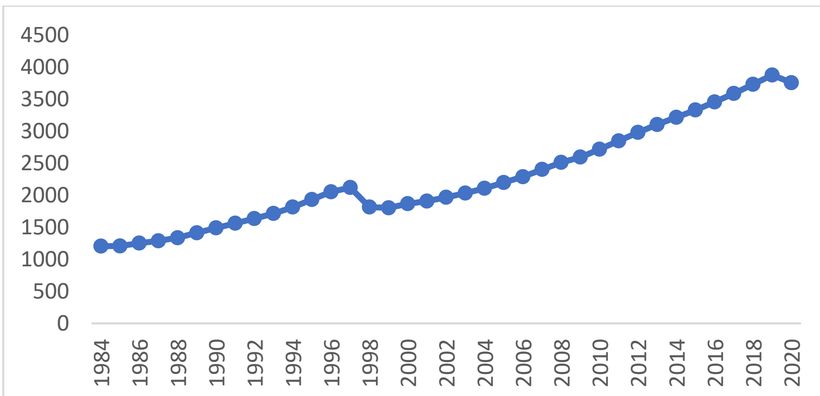

FIGURE 1. Trend of Per Capita (Constant Price 2005) in Indonesia (US Dolar), 1984-2020.

The development strategies that Indonesia implemented to accelerate economic performance was 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, namely environmental degradation, climate change, and exploitation of natural resources (Kostha, 2021). Rahman (2020) stated that economic growth requires additional production from industry, and the additional energy consumption is unavoidable, which drives carbon emissions. Alam (2022) argued that the requirements for increased economic growth undermined 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.

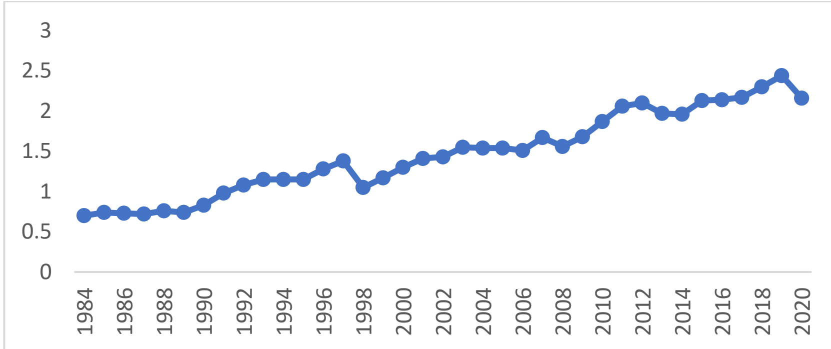

FIGURE 2. The trend of CO_2 emission in Indonesia, 1984-2020 (metrics per capita)

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 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 environmentally 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 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 & 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 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 licensing from entrepreneurs to regional heads, (2) when granting Environmental Impact Analysis licenses, (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 (2022) found that corrupt behaviour using two indices, namely the corruption index and corruption rankings, has worsened environmental sustainability in 16 countries in southern Africa. Cole and Fredrikson (2009) found that countries with weak environmental institutions will attract more polluting industries that encourage environmental damage.

Due to the mixed findings on the impacts 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, Antweiller 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. Besides that, Ahmed et al. (2017), Aye and Edoja (2017), and Musah et al. (2021) identify 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 panel data from 15 countries on energy consumption, economic growth, urbanisation, and carbon emissions. The findings indicate that urbanisation has no significant impact on environmental quality and that energy consumption will harm the environment in the long run 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 CO2 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 carbon footprint. The findings revealed that increased energy consumption and financial development would substantially increase the carbon footprint. In contrast, the relationship between economy and carbon footprint exhibited an inverted U shape, confirming the validity of EKC in Japan.

The existing literature on the relationship between corruption and environmental sustainability is active (Usman, 2022; Ganda, 2020; Wang, Zhao and Chen, 2020). According to popular belief, 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 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) 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 distortion and lower 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: (i) a higher level of corruption in Africa; (ii) corruption is negatively related to CO_2 emissions in lower-emitting countries; (iii) corruption is not a significant enough factor in higher emitting countries to explain changes in CO_2 emissions; and (iv) 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 focusing on the impacts of foreign investment, energy used and corruption in Indonesia. Thus, this research's findings could contribute to the body of knowledge. Besides, this research uses the most recent sample data and sophisticated techniques to provide some insight into the robustness of the findings.

TABLE 1: Summary of Literature Review

Author	Findings
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, respectively.
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 economy and carbon footprint exhibited an inverted U shape, 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 lower monitoring levels.
Habib, Abdelmonen and Khaled (2020)	(i) A higher level of corruption in Africa; (ii) corruption is negatively related to CO_2 emissions in lower-emitting countries; (iii) corruption is not a significant enough factor in higher emitting countries to explain changes in CO_2 emissions; and (iv) 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)	In 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. The study found that FDI increases CO_2 emissions and contributes to environmental degradation. 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. The study found that FDI increases CO_2 emissions and contributes to environmental degradation.
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.

3 Methodology

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

$$I = P \cdot A \cdot T$$

According to the model, environmental degradation rises 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. Besides, population growth can also contribute to harming the environment. This might be due to 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 his 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:

$$CO2_t = f(GDP_t, COR_t, ENY_t, FDI_t, UBG_t) \ldots (1.0)$$

where

CO2t represents environmental quality,
GDPt represents economic growth,
CORt represents corruption,
ENYt represents energy used,
FDIt represent foreign direct investments inflows,
UBGt represents urbanisation growth

The variables in equation 2 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. (2012), the log version of the tested variables can produce a consistent and reliable estimation. The log version of the model derived from Equation 1.0 can be seen as follows:

$$LNCO2_t = \delta_0 + \alpha_1 LNGDP_t + \beta_2 LNCOR_t + \sigma_3 LNENY_t + \phi_4 LNFDI_t + \tau_7 LNUBG_t + \mu_t \ldots (2.0)$$

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. Next, 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 proved by Rafindadi et al. (2018) and Balsalobre-Lorente et al. (2019a). The pollution Haven Hypothesis, addressed by Terzi and Pata (2019) and Pata et al. (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 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 suggest that the increased population caused by urbanisation triggers intensive urban economic activity, which leads to increased demand for energy and carbon emissions (Ali et al. 2019). However, some studies suggest that 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 variable based on the Unrestricted Error Correction Model (UECM) are stated below:

$$\Delta LNCO2_t = \beta_1 + \theta_0 LNCO2_{t-1} + \theta_1 LNGDP_{t-1} + \theta_2 LNCOR_{t-1} + \theta_3 LNENY_{t-1} + \theta_4 LNFDI_{t-1} + \theta_5 LNUBG_{t-1} + \\ + \sum_{i=1}^{a} \beta_i \Delta LNCO2_{t-i} + \sum_{i=0}^{b} \gamma_i \Delta LNGDP_{t-i} + \sum_{i=0}^{c} \delta_i \Delta LNCOR_{t-i} + \sum_{i=0}^{d} \lambda_i \Delta LNENY_{t-i} + \sum_{i=0}^{e} \vartheta_i \Delta LNFDI_{t-i} + \sum_{i=0}^{f} \psi_i \Delta LNUBG_{t-i} + \upsilon_t ...(3.0)$$

$$\Delta LNGDP_t = \beta_2 + \theta_0 LNCO2_{t-1} + \theta_1 LNGDP_{t-1} + \theta_2 LNCOR_{t-1} + \theta_3 LNENY_{t-1} + \theta_4 LNFDI_{t-1} + \theta_5 LNUBG_{t-1} + \\ + \sum_{i=1}^{a} \beta_i \Delta LNGDP_{t-i} + \sum_{i=0}^{b} \gamma_i \Delta LNCO2_{t-i} + \sum_{i=0}^{c} \delta_i \Delta LNCOR_{t-i} + \sum_{i=0}^{d} \lambda_i \Delta LNENY_{t-i} + \sum_{i=0}^{e} \vartheta_i \Delta LNFDI_{t-i} + \sum_{i=0}^{f} \psi_i \Delta LNUBG_{t-i} + \upsilon_t ...(4.0)$$

$$\Delta LNCOR_t = \beta_3 + \theta_0 LNCO2_{t-1} + \theta_1 LNGDP_{t-1} + \theta_2 LNCOR_{t-1} + \theta_3 LNENY_{t-1} + \theta_4 LNFDI_{t-1} + \theta_5 LNUBG_{t-1} + \\ + \sum_{i=1}^{a} \beta_i \Delta LNCOR_{t-i} + \sum_{i=0}^{b} \gamma_i \Delta LNGDP_{t-i} + \sum_{i=0}^{c} \delta_i \Delta LNCO2_{t-i} + \sum_{i=0}^{d} \lambda_i \Delta LNENY_{t-i} + \sum_{i=0}^{e} \vartheta_i \Delta LNFDI_{t-i} + \sum_{i=0}^{f} \psi_i \Delta LNUBG_{t-i} + \upsilon_t ...(5.0)$$

$$\Delta LNENY_t = \beta_4 + \theta_0 LNCO2_{t-1} + \theta_1 LNGDP_{t-1} + \theta_2 LNCOR_{t-1} + \theta_3 LNENY_{t-1} + \theta_4 LNFDI_{t-1} + \theta_5 LNUBG_{t-1} + \\ + \sum_{i=1}^{a} \beta_i \Delta LNENY_{t-i} + \sum_{i=0}^{b} \gamma_i \Delta LNGDP_{t-i} + \sum_{i=0}^{c} \delta_i \Delta LNCOR_{t-i} + \sum_{i=0}^{d} \lambda_i \Delta LNCO2_{t-i} + \sum_{i=0}^{e} \vartheta_i \Delta LNFDI_{t-i} + \sum_{i=0}^{f} \psi_i \Delta LNUBG_{t-i} + \upsilon_t ...(6.0)$$

$$\Delta LNUBG_t = \beta_5 + \theta_0 LNCO2_{t-1} + \theta_1 LNGDP_{t-1} + \theta_2 LNCOR_{t-1} + \theta_3 LNENY_{t-1} + \theta_4 LNFDI_{t-1} + \theta_5 LNUBG_{t-1} + \\ + \sum_{i=1}^{a} \beta_i \Delta LNUBG_{t-i} + \sum_{i=0}^{b} \gamma_i \Delta LNGDP_{t-i} + \sum_{i=0}^{c} \delta_i \Delta LNCOR_{t-i} + \sum_{i=0}^{d} \lambda_i \Delta LNENY_{t-i} + \sum_{i=0}^{e} \vartheta_i \Delta LNFDI_{t-i} + \sum_{i=0}^{f} \psi_i \Delta LNCO2_{t-i} + \upsilon_t ...(7.0)$$

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 Equation (3.0) until Equation (7.0) above 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 capture the short-run effects. The null of no co-integration in the long-run relationship is defined by:

$H0$: $\theta0=\theta1=\theta2=\theta3=\theta4=\theta5=0$ (there is no long-run relationship),

is tested against the alternative of

$H1$: $\theta0\neq\theta1\neq\theta2\neq \theta3\neq\theta4\neq\theta5\neq0$ (there is 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 aim to test the dynamic linkages between the potential indicators for Indonesia's environmental quality, where previous literature using panel data analysis has presented mixed and ambiguous evidence for each nation (Hossain, 2012). To get around some of the issues with panel data analysis, we used time series analysis in our study. Furthermore, to deliver reliable results, country-specific analyses like this study are required (Chandran, Sharma & Madhavan, 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 previous literature, FDI may increase global CO_2 emissions if environmental regulations are loosened in developing nations (Pao & Tsai, 2011).

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

TABLE 2: Sources of data

Variables	Description	Sources
LNCO2	CO_2 emissions (metric tons per capita)	WDI
LNGDP	GDP per capita (constant 2015 US$)	WDI
LNCOR	Corruption Perception 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 Indicator 2022.

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 root. The outcomes can be viewed in Table 3 below. Based on ADF unit root, it is found that all variables are not stationary at level. However, all variables are found to be stationary at a 1 or 5% significant level at first different. We proceed to PP unit root test to reconfirm the stationarity of each variable. PP unit root is more powerful as compared to ADF unit root. Overall, we found that LNENY is stationary at 1% at level while the rest variables are not significant. However, as we proceed to first difference, all variables are found to be significant either at 1 or 5% significant level. The mix stationarity outcome fulfils the condition for ARDL testing for the model proposed in this study.

TABLE 3: Testing ADF and PP Unit Root

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	-0.434 (0)	-2.426 (1)	-0.434 (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)	-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% of significant levels, respectively. The optimal lag length is selected automatically using the Schwarz Info Criteria (SIC) for ADF test, and the bandwidth has been selected by using the Newey–West method for PP.

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 equation suggest the rejection of the null hypothesis of no co-integration. The F statistic from this model is significant between 1 to 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 on this model.

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

Model	Max Lag	Lag order	F statistics	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 stat		Lower I(0)	Upper (1)	
10%		2.26	3.35	
5%		2.62	3.79	
1%		3.41	4.68	

Note: 1. k is a number of variables and it is equivalent to 5. 2. *, **, and *** represent 10%, 5% and 1% levels of significance, respectively. Estimation is based on Schwarz Criterion (SC).

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, function form, normality, heteroscedasticity, and stability model consisting of CUSUM and CUSUM sq tests. Based on Table 5, it is confirmed that the carbon emissions model that we focus on in this study has passed all the diagnostic tests, as shown in Table 4 below. The probability value for the first four tests is more than 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.

TABLE 5: Diagnostic Tests

(A) Serial Correlation [p-value]	(B) Functional Form [p-value]	(C) Normality [p-value]	(D) Heteroscedasticity [p-value]
0.356 [0.703]	1.241 [0.275]	1.249 [0.535]	0.878 [0.547]

Note. 1. ** represent 5% significant levels. 2. The diagnostic test 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.

We also performed CUSUM and CUSUM sq 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.

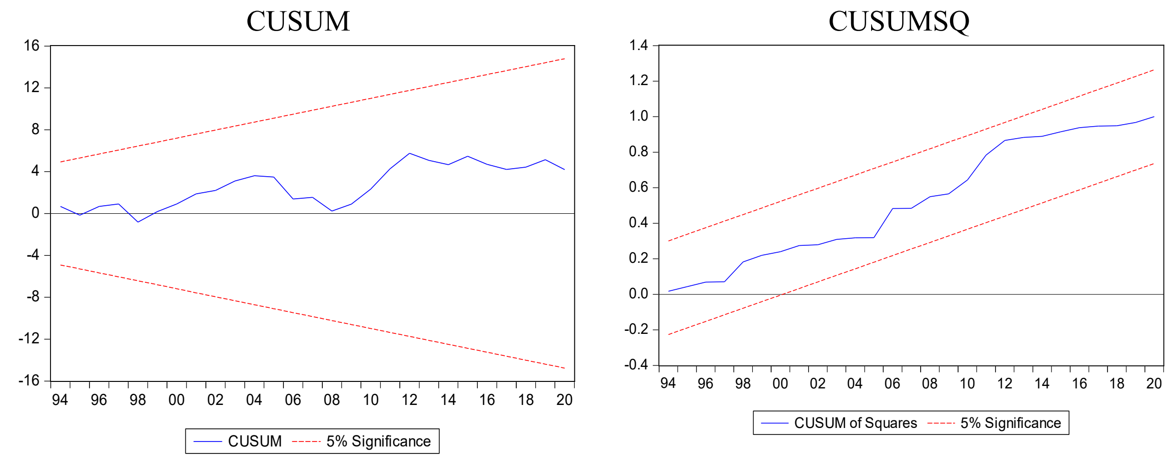

FIGURE 3 CUSUM and CUSUM Sq

Table 6 presents 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. Statically, 1% increases in LNGDP and LNCOR lead to 1.28% and 0.01% increases in carbon emissions releases. Rapid development in the country causes more pollution as compared to 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 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 per cent increase in economic growth raises CO_2 emissions by 0.31 per cent. 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 LNEY 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 (Ahmed et al. 2022; Hongqiao et al. 2022; Ridzuan et al. 2021). 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 investment focusing 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).

TABLE 6: Short run and Long run Elasticities

Short run Elasticities		Long run Elasticities	
Variables	Coefficient	Variables	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% of significant levels, respectively. 2. Δ refer to difference

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 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 and local culture.

Author contributions

Ridzuan, A.R and Pujiati, A work together on data collection and statistical analysis, and contributed to the writing of the manuscript. The rest authors help to refine each section of the paper. All authors have read and agree to the published version of the manuscript.

Conflict of interest

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

Funding

We wish to extend our 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.

Acknowledgments

This research project is a collaboration between two universities: Universiti Teknologi MARA, Malaysia and Universitas Negeri Semarang, Indonesia under Strategic Partnership Research grant.

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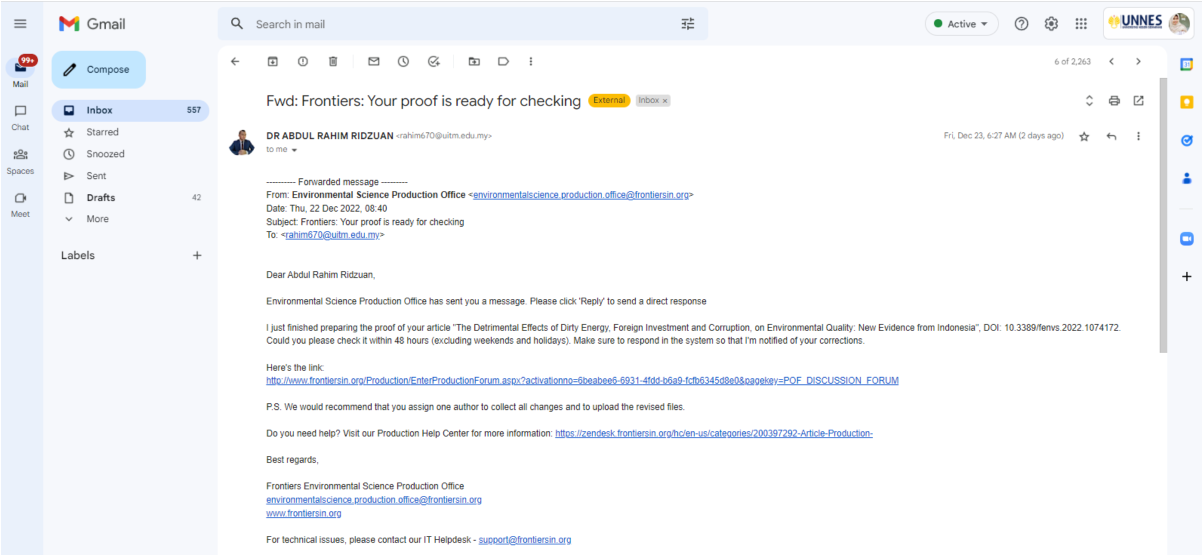
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RECEIVED 19 October 2022
ACCEPTED 14 December 2022
PUBLISHED XX XX 2022

CITATION
Pujiati A, Yanto H, Dwi Handayani B, Ridzuan AR, Borhan H and Shaari MS (2022), The detrimental effects of dirty energy, foreign investment, and corruption on environmental quality: New evidence from Indonesia.
Front. Environ. Sci. 10:1074172.
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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]

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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 domestic product (*per capita* 2005) from 1984 to 2020. The value of GDP *per capita* in

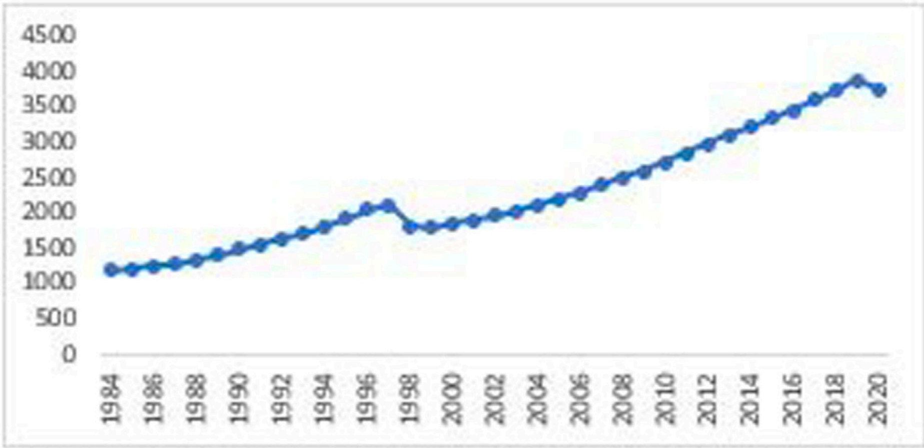

FIGURE 1
Trend of per capita (constant price 2005) in Indonesia (US dollar), 1984–2020.

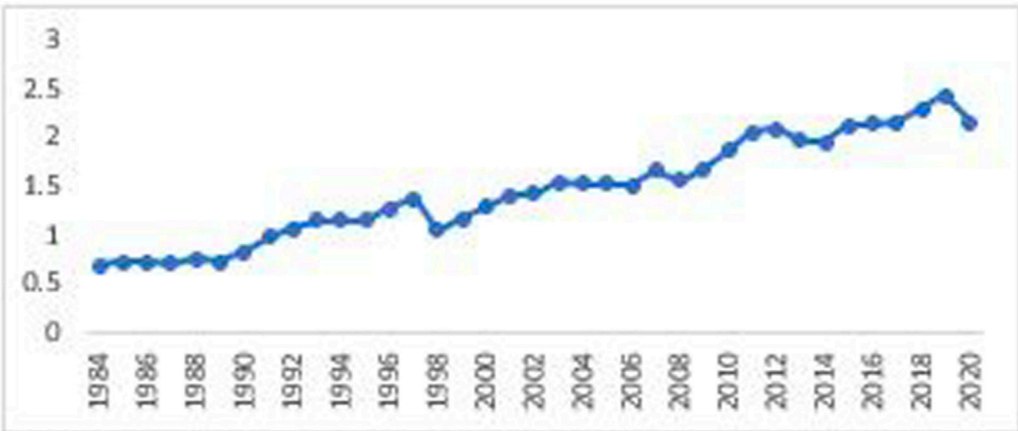

FIGURE 2
Trend of CO_2 emission in Indonesia, 1984–2020 (metrics *per capita*).

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.

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 Q11 can be written as follows:

$$I = P \cdot A \cdot T. \tag{1}$$

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:

$$CO2_t = f\left(GDP_t, COR_t, ENY_t, FDI_t, UBG_t\right), \tag{2}$$

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:

$$LNCO2_t = \delta_0 + \alpha_1 LNGDP_t + \beta_2 LNCOR_t + \sigma_3 LNENY_t + \phi_4 LNFDI_t + \tau_7 LNUBG_t + \mu_t. \tag{3}$$

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 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.

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)	In developing countries, such as most African countries, they adopted convenient environmental regulations for various 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 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. The study found that FDI increases CO_2 emissions and contributes to environmental degradation
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

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

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

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

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

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.

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

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

?0: ?0 = ?1 = ?2 = ?3 = ?4 = ?5 = 0 (there is no long-run relationship) is tested against the alternative of

?1: ?0≠?1≠?2≠ ?3≠?4≠?5≠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

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.

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 Q12 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 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.

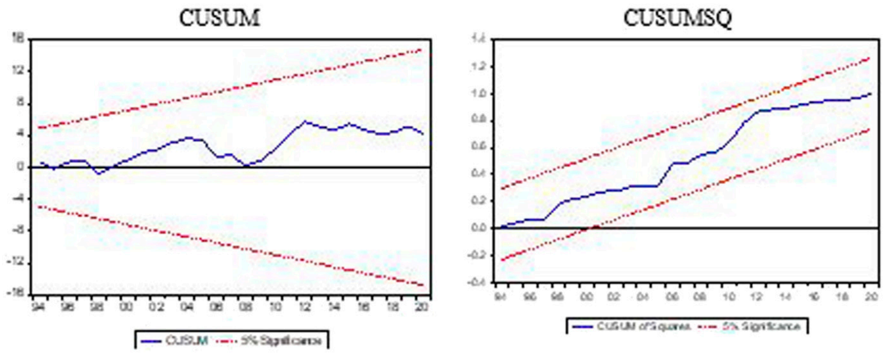

FIGURE 3
CUSUM and CUSUMSQ.

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.

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. Q13

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. Q14

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. Q15 Q16

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. Q17

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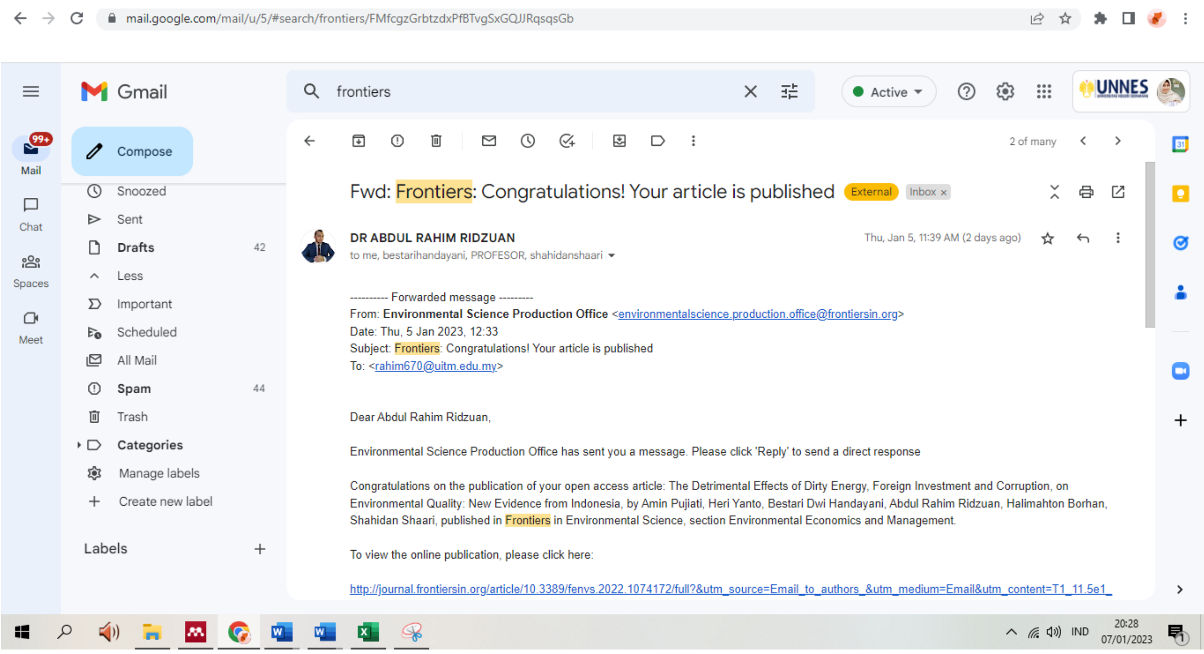

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TYPE Original Research
PUBLISHED 05 January 2023
DOI 10.3389/fenvs.2022.1074172

OPEN ACCESS

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

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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

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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

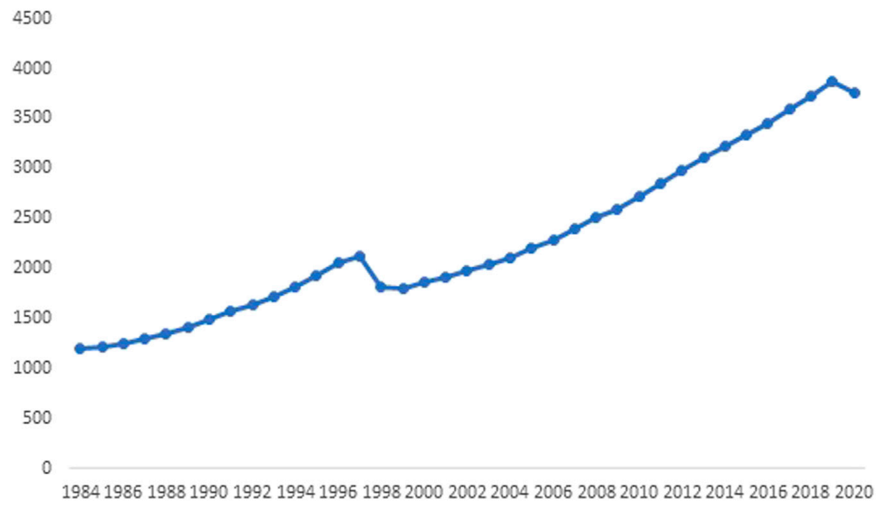

FIGURE 1
Trend of per capita (constant price 2005) in Indonesia (US dollar), 1984–2020.

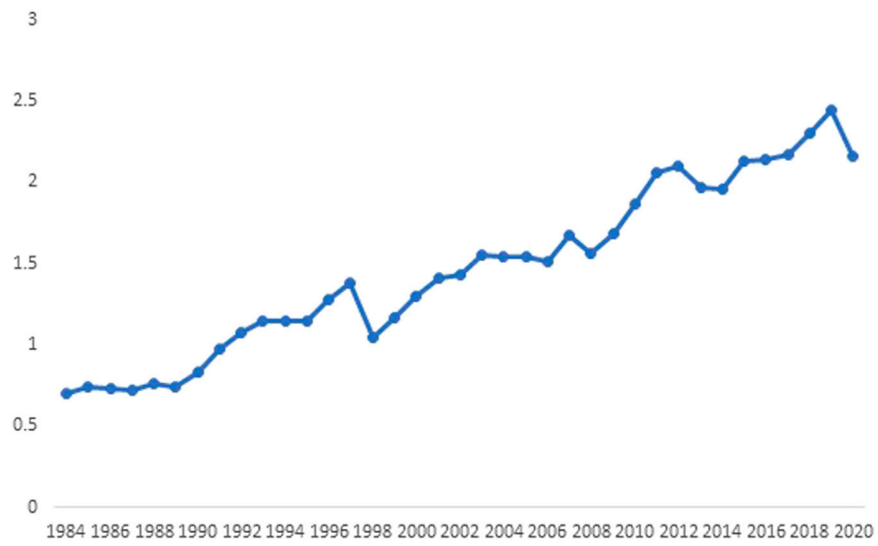

FIGURE 2
Trend of CO_2 emission in Indonesia, 1984–2020 (metrics *per capita*).

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:

$$I = P \cdot A \cdot T. \tag{1}$$

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:

$$CO2_t = f\,(GDP_t, COR_t, ENY_t, FDI_t, UBG_t), \tag{2}$$

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:

$$\begin{aligned} LNCO2_t = \delta_0 + \alpha_1 LNGDP_t + \beta_2 LNCOR_t + \sigma_3 LNENY_t \\ + \phi_4 LNFDI_t + \tau_7 LNUBG_t + \mu_t. \end{aligned} \tag{3}$$

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.

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

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

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

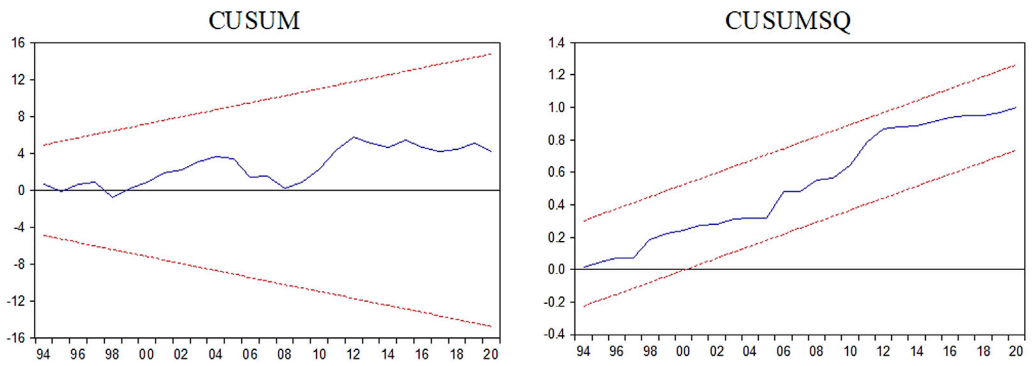

FIGURE 3
CUSUM and CUSUMSQ.

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.

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