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RESEARCH ARTICLE

Policy insight from renewable energy, foreign direct investment (FDI), and urbanization towards climate goal: insight from Indonesia

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Abstract

This study is premised on Indonesia's climate goal amidst good economic performance. To test the environmental implication of this macroeconomic performance of Indonesia, we adopt Indonesian quarterly data of 1990Q1–2018Q4 for empirical analysis. Relevant instruments in the economic performance of Indonesia such as urbanization, foreign direct investment (FDI), and renewable energy source are all adopted for accurate estimations and analysis of this topic. Different approaches (structural break test, autoregressive distributed lag (ARDL)-bounds testing and Granger causality) are all adopted in this study. Our analysis and policy recommendations are based on the short-run and long-run ARDL dynamics and Granger causality. Findings from ARDL confirmed negative relationship between carbon emission and renewable energy source, FDI, and urbanization. Also, a U-shape instead of inverted U-shaped EKC is found confirming the impeding implication of Indonesian economic growth to its environmental performance if not checkmate. From Granger causality analysis, all the variables are seen transmitting to urbanization in a one-way causal relationship. Also, FDI and renewable energy prove to be essential determinants of the country's environment development; hence, FDI is seen transmitting to both energy sources (fossil fuels and renewables) in a one-way causal relationship. Renewable energy is as well seen having two ways causal relationship with both carbon emission and fossil fuels. This result has equally exposed the significant position of the three instruments (urbanization, FDI, and renewable energy source) in Indonesian environment development.

Keywords Economic growth (GDP) · FDI · Urbanization · Carbon neutrality · Sustainable study · Indonesia

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Highlights

1. This is a time series study of Indonesia's environmental performance
2. Renewable energy, urbanization and foreign Direct Investment (FDI) are used to assess the possibility of accessing carbon neutrality in Indonesian
3. Indonesia's ambition towards mitigating carbon emission is confirmed with the three instruments (renewable energy, FDI and urbanization)
4. Conclusion is based on policy framing towards reducing the fossil fuels impact on Indonesia's environmental performance

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Introduction

Foreign direct investment (FDI) is a crucial microeconomic and macroeconomic tool for both developing and emerging economies. To invest efficiently in a foreign country, a company must have ownership that no other company has. However, the foreign country must offer advantages in terms of location, productivity, and operations. A robust FDI regime has the propensity to engender higher-income generation, spur job creation opportunities (reduce unemployment), and enhance diversification. For instance, Indonesia is regarded as one of the largest economies in Southeast Asia because of its vigorous fiscal management and sustained economic growth over the years. Through structural reforms, the country's foreign investment (inflow) increased to 14% in 2019, largely in gas, electricity, water, and transportation. The Indonesian government implemented policies that have contributed to their growth in investment. Some of the policies are tax incentives for investment in major economic sectors, law enforcement, and business certainty, cuts in interest rate tax on exporters, and energy tariffs for industries. These policies have qualified Indonesia to rank as the 17th out of 20 top host countries based on the source of investment. Japan is the largest and the USA is the 5th source of investment (UNCTAD 2020).

FDI has declined from the year 2020 mainly due to the uncertainty over the development of the covid-19 pandemic which has adversely led to the world economic decline. The fall in foreign investment was more in the developed economies, fall by 69% reported by UNCTAD (Canton 2021). The flow of FDIs to the USA indicated a decline mostly in the primary sector with 49%, making the foreign investors discrete with their capital to productive assets. Furthermore, the uncertainty affects the flow of FDIs to developing economies as well with a 12% fall in FDI inflow, reported with a fall of − 4% in Asia, − 18% in Africa, and − 37% in Latin America and the Caribbean. However, despite the pandemic, Indonesia is expecting more investment in 2021. The government has approached bona fide companies to invest in the country. Pandemic notwithstanding, statistics from investment coordinating board (bkpm) indicates the growth of investments in Indonesia. The foreign investment grew to 2.1% (US$58.8 billion), 1.11% higher than the target. However, suggests an increase of domestic investment by 7%, while foreign direct investment reduced by 2.4%.

Notwithstanding the significance of FDI in promoting growth, it also has disadvantages. It can act as a monopoly which will affect the domestic markets. Foreign investment has improved its benefits globally as well as in Indonesia over the last decades. FDI flows have influence economic growth in Indonesia positively. Many researches have proved its benefits on how foreign investment added value to both foreign investors and domestic (local) firms. To improve an economy's production capacity through FDI flows, the quality of export should be improved and barriers should be minimized or removed to enhance competition (Khaliq and Noy 2007; Sjöholm, 2017). Correspondingly, policies should be enforced to lighten tariff and labor market arrangements because excessive tariff on imported inputs by host country discourages multinational firms thereby leading to a reduction in FDI inflow (Ahmad et al., 2018). Khaliq and Noy (2007) opined that increase in FDI improves the economic growth of Indonesia. It equally shows that the impact of FDI on the non-oil and gas industry, electricity and water, retail and wholesale trade, transport and communications, and hotels and restaurant has positive impact on the economy. However, FDI impact on mining and quarrying reduces economic growth. Katircioglu (2009), Mahmood and Ahmed et al. (2016), and Effendi and Soemantri (2003) asserted that not all sectors benefit from foreign investment which indicates that more attention should be given to sectors that contribute to economic growth. However, other studies believe it does not affect economic growth (Kersan-Škabić and Zubin (2009).

According to the World Resources Institution (WRI), Indonesia is the 5th largest emitter of greenhouse gasses in the world due to the transmutation of carbon-rich sources, ecological and social reactions. The Indonesia Administration decided to reduce greenhouse gas emissions to the minimum of 26 percent by 2020 and 41 percent with financial support from developed countries and also plan to minimize emissions by 2030 to below 662 MtCo2e through the reduction of forest debasement to attain the nation's target of environmental sustainability (World Bank Country Director for Indonesia). Indonesia has notable fossil fuel types which include oil, coal, and natural gas, and renewable energy resources. In 2013, Indonesia became the largest exporter of coal (Statistics, IEA 2014). However, it generates power from renewable energy (solar, wind, hydro, and geothermal of 788.00 MW of power). Sasana and Ghozali indicated that subsidies on fossil fuel enhance the increase of emissions which reduce the environmental quality of Indonesia. Nonetheless, the environmental effect on both the present and future growth of Indonesia is of great importance to policymakers. According to United Nations' Sustainable Development Goals (SDGs), individual countries are encouraged to work towards curtailing climate change by maintaining good environmental quality through carbon neutrality. According to the United Nations' Development Program 2020, the Government of Indonesia has made significant efforts to implement the SDGs into its economic and social development planning process in order to achieve economic growth, environmental sustainability, employment, and poverty reduction. These goals are outlined in Indonesia's 2030 SDG Road Map.

To this end, the present study is targeted on assessing the ability of Indonesia to achieving carbon neutrality through energy transition (shift to renewable source of energy), FDI, and urbanization policies. Indonesia is one of the largest and fastest growing economies in Southeast Asia. As noted before, Indonesia is positioned as among the best performing economies in Southeast Asia because of its vigorous fiscal management and sustained economic growth over the years. The country's foreign investment inflow increased to 14% in 2019, largely in gas, electricity, water, and transportation because of the viability of its macroeconomic reforms. Some of the reforms are policies targeted to enhance growth in investment in the entire economy. Among the policies are tax incentives for investment in major economic sectors, law enforcement and business certainty, cuts in interest rate tax on exporters, and energy tariffs for industries. Indonesian economy is positively overhauled and ranked 17th out of 20 top host countries based on the source of investment. As emerging country that is characterized with growth and investment potentials especially in the areas of gas, electricity, water, and transportation, there is likelihood of great utilization of energy sources which has potentials in impacting environment and climate change through greenhouse gas.

Against this backdrop, we select the macroeconomic and energy cum environment variables (real GDP per capita and its square, FDI, urbanization, fossil fuels, and renewable energy source) to test the sustainable development of the country with respect to environment. This defines the objective of this study which is to investigate the possibility of Indonesia to mitigate carbon emission with the three policies (FDI, renewable energy, and urbanization) to enhance carbon neutrality of the country and also examine if there is any relationship between FDI, renewable energy, urbanization, and environmental quality. The objective is further divided into 3 different hypothetical questions as follows: (a) Is Indonesian renewable energy sector capable of mitigating its carbon emissions? (b) What is the implication of urban population increase in Indonesia towards its environmental performance? (c) Is FDI inducing or mitigating Indonesian carbon emissions? Answers to the above hypothesized questions will add to the energy-environmental literature. This study through its findings will have great implications to the other emerging and developing countries with similar features like Indonesia. For clear insight to this subject, authors aim to examine the empirical evidence of the impact of FDI inflows and renewable energy on the environmental quality of Indonesia by employing approaches (such as structural break; bound cointegration test and symmetric ARDL dynamics model). Our study will add to the literature through the revealing power of the three policies in curtailing emission rate and fostering carbon neutrality in Indonesia.

The rest part of this study is as follows: the "Literature review" section, "Methodology, modeling, and data" section, "Empirical results and discussion" section, and "Concluding remark and policy framing" section.

Literature review

With the rising flows of FDI into the Indonesian economy, it will be instructive to explore the major impact of the rise in FDI inflows on the environmental sustainability of the nation. Many studies have confirmed the positive influence of FDI on environmental quality (Udemba, 2019; Haug and Ucal, (2019); ,, Sarkodie and Strezov, (2019)).

Philip et al. (2021) analyzed the cause of foreign direct investment, urbanization, income, and energy used on the Turkish environment amid the global economic plunge. The study indicated that all the variables contribute to environmental degradation in Turkey. It suggested that policies should be fixed on green investment inflow and encourage the use of renewable energy. Jun et al. (2018) applied the wavelet tool from 1982–2016 to analyze the impacts of FDI and economic growth on pollution. Their findings confirm that foreign investment positively impacts environmental degradation indicating that an increase in FDI increases emissions both in the short-run and long run in China. Abdouli and Hammami (2017) indicated a rise in foreign investment and income increases pollution. The study of Sasana et al. (2018) states that high economic growth in Indonesia reduces environmental degradation, while foreign investments have a positive impact on CO2 emissions showing that the activities of the multinational companies reduce the quality of the environment.

However, others indicate that FDI reduces CO2 emissions (Shahbaz et al., 2019, Joshua et al. 2020). Atici (2012) found no evidence that FDI influences CO2 emission negatively showing that foreign investment in ASEAN economies does not lead to increasing pollution due to operating in nonpolluting sectors. Merican et al. (2007) test the impact of FDI on the environment of some Southeast Asian developing (Indonesia, Malaysia, Singapore, Thailand, and the Philippines) countries. Employing the autoregressive distributive lag (ARDL) model, the study found that the inflow of FDI increases environmental degradation in Thailand, Malaysia, and the Philippines, whereas increase in foreign investment decreases environmental pollution in Indonesia and shows insignificant relation in Singapore. Bachri and Normelani (2020) evaluate the nexus of disposable income and environmental degradation on FDI in Indonesia utilized the ARDL and Granger causality test from 1960–2018. The study revealed that FDI has a significant impact on environmental pollution and income.

Renewable energy is an important source of energy. It minimizes the effect of greenhouse gas emissions (types of air pollution) by reducing the use of fossil fuels (coal, gas, oil). It is also important because it reduces the dependence on imported fuels and creates economic development and jobs in manufacturing and installation. The problems or challenges that slow the development of renewable energy in Indonesia are policy uncertainty, financing barriers, low renewables manufacturing volume, and market barriers (Müller 2017). Sugiawan and Managi (2016) investigate the EKC and the impact of foreign direct investment, energy production from renewable energy sources, and on environmental pollution in Indonesia. The outcome of the analysis reveals the insignificant support for EKC, and energy production increases the level of CO_2 emissions in the period of the study. On the contrary, renewable energy has a significant and beneficial influence in the reduction of environmental pollution. Finally, an increase in the total factor of productivity decreases emissions both periods. Their study suggests that decrease in subsidies on fossil fuels should be encouraged to minimize the use of fossil fuel for electricity consumption. This will in return enhance renewable energy consumption by providing incentives for more efficient and cleaner technologies which will as well enhance Indonesia's electricity generation. Shezan et al. (2017) revealed that hybrid system is significantly favorable to the environment by reducing the effect of CO_2 emissions in Indonesia. Their study suggests cost reduction and suitable control systems for hybrid energy system, and also maximizes the available renewable energy sources. Indeed, studies by for Indonesia and Thailand, Qi et al. (2014) for China, and Sebri and Ben-Salha (2014) for BRICS confirm that increase in renewable energy use reduces the effect of CO_2 emissions. Udemba et al. (2021) indicate that carbon emissions may be reduced by using renewable energy to achieve environmental quality, based on their findings from both symmetric and asymmetric models. According to Usman and Makhdum (2021), increasing the usage of renewable energy reduces the ecological footprint, which benefits the environment in the long run. The study suggested that policymakers should support the use of renewable energy to accomplish sustainable development goals. Also, Usman and Hammar (2021) stated that renewable energy utilization significantly enhances environmental quality. Moreover, renewable energy, according to several studies, reduces pollutants in the environment (Bashir et al., 2021; Usman and Balsalobre-Lorente, 2022; Ridzuan et al. 2020; Huang et al., 2022).

Urbanization in Indonesia has increased over the years just like any other country. Jakarta is the largest city in Indonesia which is the nation's capital with about 10 million populations (Aydogan 2021). People move from rural to urban areas for job opportunities, good health care, social benefits, and services. The urban area creates more opportunities for innovation, industrialization, and commercialization. Apart from these rural–urban movement benefits, it also has its negative side such as dismantling of habitats and increase environmental pollution. Some researchers analyzed the impact of urbanization on economic growth and environmental sustainability. The study of Sasana and Aminata (2019) stated that an increase in the population of urban areas increases investment activities through the use of higher oil fuel which later enhances the rates of CO_2 emissions. This indicates that urbanization activities may have a positive influence on environmental pollution by increasing pollution in urban areas. Ali et al. (2019) proved that urbanization influences emissions. Government policies are needed for green technology to control pollution from industrial and residential areas. Anwar et al. (2020) stated that the increase in urbanization and economic growth has increase the pollution in East Asia. The study encourages sustainable urbanization and the use of green resources to stimulate economic stability without impacting the environment negatively. According to Bashir et al. (2022), urbanization activities may have a positive impact on environmental problems by increasing pollutants in urban areas. Also, Balsalobre-Lorente et al. (2022) indicated that urbanization have an adverse impact on the environment. However, Yanga et al. (2021) stated that urbanization reduces pollution levels. Inferring that as the level of urbanization rises and human resources improve, environmental sustainability would improve. Also, Udemba et al. (2021) specified that urbanization reduces carbon emissions.

Summarily, impacts of the selected variables are hypothesized from the highlighted literature in this section as follows:

H0: FDI impacts favorable on both economic growth and environment quality

FDI has been studied with mixed findings. Hence, FDI improves an economy's production (Khaliq and Noy 2007; Sjöholm, 2017), FDI impact on mining and quarrying reduces economic growth (Katircioglu, 2009), and Ahmed et al. (2016) and Effendi and Soemantri (2003) asserted that not all sectors benefit from foreign investment. However, other studies believe it does not affect economic growth (Kersan-Škabić and Zubin 2009). Many studies (Udemba 2019; Haug and Ucal, 2019; Sarkodie and Strezov, 2019) have confirmed the positive influence of FDI on environmental quality. Philip et al. (2021) analyzed the cause of foreign direct investment, urbanization, income, and energy used on the Turkish environment amid the global economic plunge. The findings confirm that all the variables contribute to environmental degradation in Turkey. Their study suggested that policies should be fixed on green investment inflow and encourage the use of renewable energy. Jun et al. (2018) confirmed that foreign investment positively impacts environmental degradation via emissions both in the short run and long run in China. Abdouli and Hammami (2017) indicated a rise in foreign investment and income increases pollution. The study of Sasana et al. (2018) states that high economic growth in Indonesia reduces environmental degradation, while foreign investments have a positive impact on CO_2 emissions. However, others (Shahbaz et al., 2019; Joshua et al. 2020) indicate that FDI reduces CO_2 emissions. Atici (2012) found no evidence that FDI influences CO_2 emission negatively showing that foreign investment in ASEAN economies does not lead to increasing pollution due to operating in nonpolluting sectors. Merican et al. (2007) found that the inflow of FDI increases environmental degradation in Thailand, Malaysia, and the Philippines, whereas increase in foreign investment decreases environmental pollution in Indonesia and shows insignificant relation in Singapore. Bachri and Normelani (2020) revealed that FDI has a significant impact on environmental pollution and income.

H0: Renewable energy impacts favorable on both economic growth and environment quality

Sasana and Ghozali indicated that subsidies on fossil fuel enhance the increase of emissions which reduce the environmental quality of Indonesia. Sugiawan and Managi (2016) investigate the EKC and the impact of foreign direct investment, energy production from renewable energy sources, and on environmental pollution in Indonesia. The outcome of the analysis reveals the insignificant support for EKC, and energy production increases the level of CO_2 emissions in the period of the study. Shezan et al. (2017) revealed that hybrid system is significantly favorable to the environment by reducing the effect of CO_2 emissions in Indonesia. Indeed, studies by Viccakusumadewi and Limmeechokchai (2017) for Indonesia and Thailand, Qi et al. (2014) for China, Sebri and Ben-Salha (2014) for BRICS confirm that increase in renewable energy use reduces the effect of CO_2 emissions. Findings from (Anwar et al., 2021) confirm that the renewable energy consumption leads to a decrease in CO_2 emissions across all the quantiles (10th to 90th). Findings from Nathaniel et al. (2021) confirm that renewable energy decreases emissions and mitigates environmental deterioration.

H0: Urbanization impacts favorable on both economic growth and environment quality

Some researchers analyzed the impact of urbanization on economic growth and environmental sustainability. The study of Sasana and Aminata (2019) states that an increase in the population of urban areas increases investment activities through the use of higher oil fuel which later enhances the rates of CO_2 emissions. This indicates that urbanization activities may have a positive influence on environmental pollution by increasing pollution in urban areas. Ali et al. (2019) proved that urbanization influences emissions. Government policies are needed for green technology to control pollution from industrial and residential areas. Anwar et al. (2020) stated the increase in urbanization and economic growth has increase pollution in East Asia. Energy consumption urban population granger cause to CO_2 emission in ASEAN-5 countries (Batool et al., 2021). Findings from Nathaniel (2021) indicate that urbanization, economic growth, and energy consumption increase environmental degradation.

Theoretical background

Our study is anchored on the transformed version of IPAT (STIRPAT) model according to Dietz and Rosa (1994). IPAT model (Ehrlich and Holdren, 1970) gives insight on the environmental impact of human agents which are most times measured with three basic instruments (population, wealth, and technology). This model was first developed in the 1970s with hypothesis of environmental effects from the three factors. The assertion of IPAT model is the multiplicative power of the instruments (population, wealth, and tech) in determining the environment without the individual ability of each variable in determining the environment. The conventional IPAT model takes the form:

$$I = PAT$$

where I denotes carbon emission which represents environment, P denotes population, A denotes wealth which is represented with real GDP per capita, and T denotes technology.

After a while, changes were observed and made in IPAT model because of its shortcomings. IPAT was later transformed into STIRPAT model by Dietz and Rosa (1994) to have a mathematical identical by showing the stochastic impacts of the instruments through regression. This accommodates application of quadratic or other polynomial style of wealth (GDP) in testing EKC hypothesis. STIRPAT model has the capacity to test the empirical analysis of the impacts of the instruments on the environment. This can be done on individual bases by controlling other variables while testing the effect of one instrument on the environment. Also, environmental Kuznets curve (EKC) was adopted as among the theories in this study. EKC hypothesis as developed by Simon Kuznets (1955) was intended to test the income inequality and was later adopted by some environment economies to test the effect of income (GDP) growth on weather development. The underlined part of EKC hypothesis is the turning point that exists between income (GDP) growth and environment. It is assumed that the initial stage of economic growth will undermine the atmosphere condition till it gets to a certain point where the impact will turn to positive on environment. Different shapes (U-shape, N-shape, and inverted U-shape) are expected to exist depending on the interaction of economic growth and environment.

Methodology, modeling, and data

Our study is modelled according to the extended version of IPAT (STIRPAT) and ARDL-bound testing. IPAT was first introduced by Ehrlic and Holdren (1970) for the analysis of human impact on environment. Following the introduction of this model, some scholars (Harrison, 1994) adopted this model for analysis of human factors in determining the environment condition. Three instruments (population, affluence, and technology) were adopted according to Ehrlic and Holdren to expose the part played by human agents in shaping the quality of environment. In attempt to include statistical testing and inference in the IPAT theory, Dietz and Rosa (1994, 1998) expanded IPAT to STIRPAT. The latest version of IPAT (STIRPAT) explains the stochastic involvement of human agents in environment development through population, affluence, and technology. Asides from suitability of STIRPAT model in empirical and hypothesis testing, it also allows the expansion of the model to include other regressors (York et al., 2003a,b) and their functional forms such as quadratic or other polynomial version apart from the three basic instruments in the model. Hence, EKC hypothesis and other explanatory variables are all accommodated in STIRPAT model. STIRPAT is modelled as follows:

$$I = \alpha P^b A^c T^d e \tag{1}$$

From Eq. 1, α is the constant, while b, c, and d are the exponents of the instruments (P, A and T) to be estimated. e is the error term. The logarithmic form of Eq. 1 is as follows:

$$lI = a + blP + clA + dlT + e \tag{2}$$

Part of the properties (a, b, c, d, and e) of Eq. 2 has been defined in Eq. 1. Specifically, a, b, c, and d in Eq. 2 are the coefficients of the instruments (population, affluence, and technology). The coefficients explains the level of change that existed in the dependent variable (I) due to the percentage change in the explanatory variables (P, A, and T). As remarked in the above, the ability of STIRPAT to accommodate other instruments apart from the three basic instruments and equally accommodate the quadratic form of the instruments, this present study includes other sensitive instruments that are important in studying Indonesian environment performance. Hence, FDI, renewable and non-renewable energies and GDP^2were utilized by scholars like Zhang and Zhao (2019) and Guo et al. (2019) have utilized the expanded form of STIRPAT with inclusion of other variables. We also adopt urban population as proxy to population, GDP per capita (constant, 2010) as proxy to affluence, and FDI as proxy to technology. We adopt FDI in place of technology in this study because of its multifaceted position in both economic growth and environmental performance through direct and indirect effects. Through FDI, direction effect of technology is possible through introduction of innovated technologies via importation by the foreign companies. This could be informed of bringing in new and enhanced carbon mitigating machines and transferring of expatriate into the host economies. Also, the indirect effect of FDI is possible through spillover effect such transferring the skills and knowledge of the foreign expatriates to the local actors in manufacturing sectors. This has significant effect both on the economic and environment performance, hence, creating room for economies of scale and job opportunities, and moderation of the emission and pollution rate due to the newly introduced innovated technologies. Other scholars (Hübler and Keller, 2010; Javorcik and Spatareanu, 2008; Keller, 2004) have equally adopted FDI in place of technology in determining environmental performance. Therefore, the expanded STIRPAT model with inclusion of all the instruments in this study is as follow:

$$\begin{aligned} lCO_{2t} &= a_o + a_1 lU.P_t + a_2 lY_t + a_3 lY^2 + a_4 FDI_t + a_5 lFoss_t \\ &+ a_6 lR.E_t + a_7 DUM1_t + a_8 DUM2_t + e_t \end{aligned} \tag{3}$$

where $lCO_2, lU.P, lY, lY^2, FDI, lFoss, lR.E, DUM1, DUM1, and e$ denote carbon dioxide emission, urban population, GDP per capita and its squared (constant, 2010), foreign direct investment (%GDP), non-renewable energy consumption as proxy by fossil fuels (i.e., summation of crude oil, natural gas, and coal in millions tonnes oil equivalent), renewable energy consumption (million tonnes of oil equivalent), dummy variables for structural break, and the error term. All the variables except FDI are all expressed in natural logarithm. The variables except environment indicators (carbon emission, fossil fuels, and renewable energy) are all sourced from the 2018 updated World Bank Development Indicators (WDI). All the environment indicators are sourced from the 2019 British Petroleum World Energy statistics. Considering the objective of this study, that is, assessing carbon neutrality of Indonesia with the selected variables (renewable energy, FDI and urbanization), we adopted carbo dioxide emission (CO_2) as the best indicator for measuring the environment. Carbon emission tends to be major contributor to the greenhouse gas emission with almost 76 percent of the gas Intergovernmental Panel on Climate Change (Woodward et al. 2014). Indonesia case is unique with FDI and renewable energy consumption showing evidence of mitigating carbon emission in most some studies (Udemba et al., 2019 for Indonesia). Indonesian quarterly data of 1990Q1–2018Q4 are utilized in this study. Instrument and their measurements are defined and summarized in Table 1 below. Also, the trend of the adopted instruments of this study is displayed in Fig. 1.

Moreover, we further the modelling of this present study to ascertain the existence of cointegration. We modelled this with autoregressive distributed lag (ARDL)-bound testing. ARDL-bound approach is preferred to other approaches in cointegration estimates (Pesaran et al., 2001). Part of the advantages of ARDL–bound testing over other approaches is the ability to accommodate multiple forms of integrations among the series. Accommodation of the sample size irrespective of the size is part of the advantages of ARDL. There is no stringent condition before the adoption of ARDL except the avoidance of second order of integration I (2). Following this, we modelled the cointegration according to the ARDL-bound testing with inclusion of both short-run and long-run estimates with error correction model (ECM) as follow:

Table 1 Summary of the instruments

Numbers	Variables	Short form	Definition/measurements
1	Carbon emission	CO_2	Carbon dioxide emission in million tonnes of carbon dioxide, in natural log and retrieved from the 2019 British Petroleum World Energy statistics
2	GDP per capita	Y	Economic growth proxy by gross domestic product (GDP) per capita (constant, 2010), in natural log and retrieved from the 2018 updated WDI
3	Squared GDP per capita	Y^2	Economic growth proxy by gross domestic product (GDP) per capita (constant, 2010), in natural log and retrieved from the 2018 updated WDI
4	Urban population	U.P	Urban population in natural log and retrieved from the 2018 updated WDI
5	Fossil fuels consumption	Foss	Non-renewable (fossil fuels) consumption in natural log and retrieved from the 2018 updated WDI
6	Foreign direct investment	FDI	Foreign direct investment inflow as percentage of GDP and retrieved from the 2018 updated WDI
7	Renewable energy consumption	R.E	Renewable energy consumption in natural log and retrieved from the 2018 updated WDI

Authors' construction

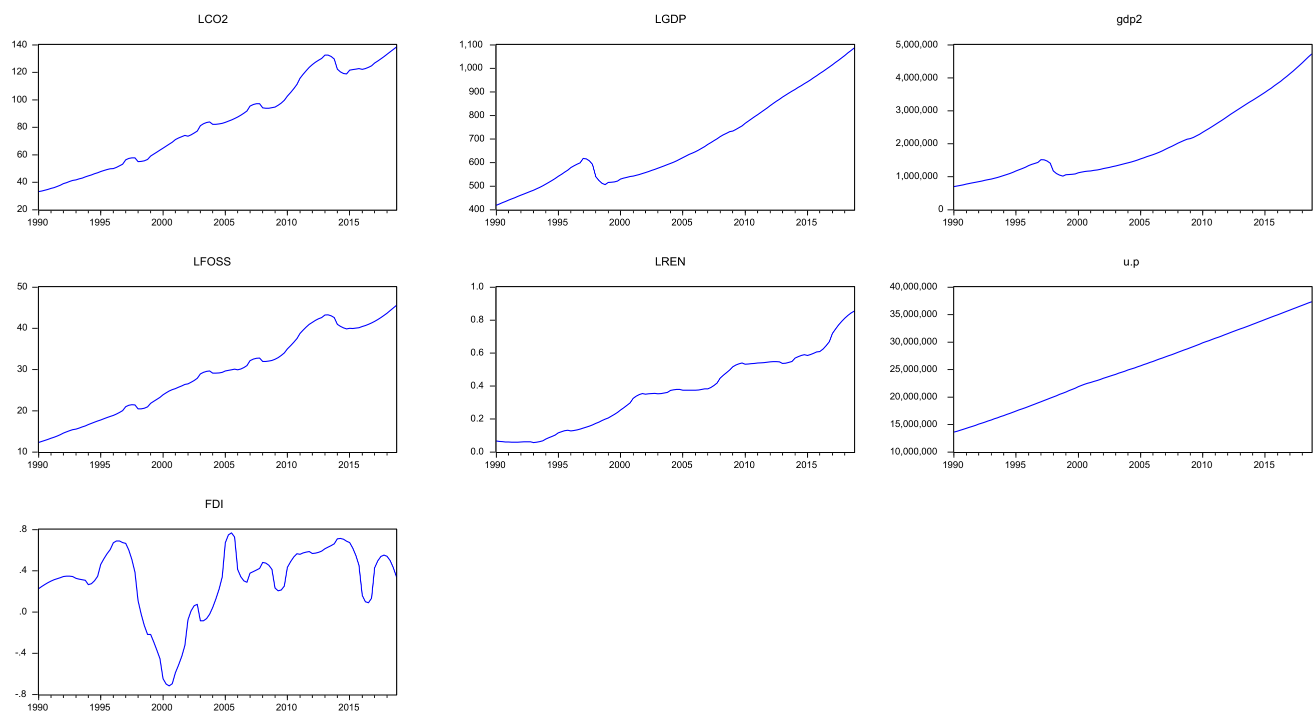

Fig. 1 Trends of the instruments as displayed

$$\Delta lCO_{2_t} = b_0 + b_1 lCO_{2_{t-1}} + b_2 lU.P_{t-1} + b_3 lY_{t-1} + b_4 lY^2_{t-1} + b_5 FDI_{t-1} + b_6 lFOSS_{t-1} + b_7 lR.E_{t-1} + b_8 lDum1_{t-1} + b_9 lDum2_{t-1} \sum_{i=0}^{s-1} \varnothing_1 \Delta lCO_{2_{t-i}} + \sum_{i=0}^{t-1} \varnothing_2 \Delta lU.P_{t-i} + \sum_{i=0}^{t-1} \varnothing_3 \Delta lY_{t-i} + \sum_{i=0}^{t-1} \varnothing_4 \Delta lY^2_{t-1} + \sum_{i=0}^{t-1} \varnothing_5 \Delta FDI_{t-i} + \sum_{i=0}^{t-1} \varnothing_6 \Delta lFOSS_{t-i} + \sum_{i=0}^{t-1} \varnothing_7 \Delta lR.E_{t-i} + \sum_{i=0}^{t-1} \varnothing_8 \Delta lDum1_{t-i} + \sum_{i=0}^{t-1} \varnothing_9 \Delta lDum2_{t-i} + ECM_{t-i} + \varepsilon_t \quad (4)$$

From Eq. 4, some of the properties and the instruments (carbon emissions, urban population, GDP per capita, squared GDP per capita, FDI, Foss, renewable energy, and Dum) have been defined from other Eqs. 1–3. The remaining properties such asb_i, $\varnothing_i$ (i = 1, 2, etc.), $\sum, \Delta, andECM_{t-i}$ are coefficients of long run (b_i) and short run ($\varnothing_i$), summation of short run and differenced form of the instruments ($\sum, \Delta$), and the error correction model (ECM_{t-i}). From the ARDL-bound testing model, cointegration is estimated by comparing the values of F and T-stats with the critical values of upper bounds. Hence, if the values of the F and T-stats are greater than the critical values of the upper bound test at 1, 5, and 10 percent significant values, it is concluded that cointegration exist and vice versa. If the values of F and T-stats fall in between the upper and lower bounds, the outcome is said to be inconclusive. This analysis is anchored on a hypothetical statement against or in support of the existence of cointegration. The null hypothesis is against the existence of cointegration, while the alternative hypothesis is in support of the existence of cointegration. The two hypotheses are expressed as follows: null hypothesis (H_0): $b_i = 0$ and the alternative hypothesis (H_1):$b_i \neq 0$.

Methodologies adopted in our study include summary and descriptive statistics, stationarity tests with conventional and structural break approaches, autoregressive distributed lag (ARDL)-bound tests, and Granger causality estimates. Diagnostic test is part of the analysis which is done with serial and autocorrelation tests, heteroscedasticity test, and cumulative sum and cumulative sum square tests. Application of descriptive statistics helps in determining the normal distribution of the data with both Jarque–Bera, skewness, and kurtosis. The stationarity test is applied for the determination of the order of the integration among the series. Conventional applications (augmented Dickey and Fuller, 1979; Philp-Perron, 1990 and Kwiatkowski et al., 1992) of stationarity tests are applied with Zivot and Andrews (1992), structural break estimate to test for the unit root, and the order of integration among the series. Most times, the structural shock in form of macroeconomic policies or natural events (Adedoyin et al., (2020) may constitute stationarity of the series when tested with conventional approaches, but when structural break test is applied, it will unveil the real unit root of the series. We applied ARDL-bound test for the estimation of cointegration. Granger causality is estimated with pairwise Granger causality method.

Empirical results and discussion

Descriptive statistics

Normal distribution of the statistics utilized in this study is done with descriptive statistics. Result of the descriptive statistics with respect to Jarque–Bera and Kurtosis confirmed that the data are normally distributed with the values of the kurtosis fall below 3 except for the case of FDI (Table 2).

Stationarity test

Unit/stationarity test is performed with both conventional and structural break approaches as remarked from the methodology section. The output from the both approaches confirmed mixed order of integration among the series. This confirmed that stationarity of the instruments took place both at level I(0) and first difference I(1). Moving further, structural breaks are noticed in the following years: 2010q4 and 2013q2 for carbon emission and Foss, 2000q2 and 2003q2 for FDI, 1997q2 and 1997q3 for economic growth (GDP), 2013q2 and 2014q2 for renewable energy, and 2000q2 and 2001q1 for urban population. Looking at the structural break tests output, it is deduced that the breaks took place from 1997q2 to 2014q2 and this is within the specified period (1990Q1–2018Q4) chosen for this study. Considering the break dates and events related to the highlighted date, it is obvious that the stationarity of the variables could be tampered with. Among the events that caused shock to most of the economies of the world are the financial shocks of 1997/1998 and 2008/2010, and these dates are reflected in our structural break tests for economic growth and fossil fuels energy. Even physical assessment of the trend of the instruments as shown in Fig. 1, it is observed that breaks that left the Indonesian economy in a permanent shock took

Table 2 Descriptive statistics

Variables	L CO_2	L Y	L Y^2	LFOSS	LREN	LU_P	FDI
Mean	83.87	680.10	1992	28.98	0.365	2528	0.299
Median	83.20	615.0	1511	29.46	0.375	2520	0.348
Maximum	138.5	1087	4727	45.59	0.854	3734	0.768
Minimum	33.15	418.7	7011	12.34	0.057	1361	−0.716
Std. Dev	32.41	185.8	1106	9.905	0.219	6954	0.352
Skewness	0.084	0.635	0.924	−0.012	0.192	0.018	−1.190
Kurtosis	1.684	2.183	2.637	1.737	2.115	1.818	3.940
Jarque–Bera	8.503	11.02	17.15	7.713	4.503	6.759	31.67
Probability	0.014	0.004	0.0002	0.021	0.105	0.034	0.000
Sum	9729	7899	2.31E+08	3361	42.37	2.93E+09	34.78
Sum Sq. Dev	1208	3972	1.41E+14	1128	5.505	5.56E+15	14.18
Observations	116	116	116	116	116	11	

Authors' computation with Eviews

place within the identified periods as reflects in the structural break outputs. Both the outputs of the structural break tests and the conventional unit root tests are displayed in Tables 3 and 4.

Cointegration and linear relationships

Cointegration and dynamic analysis of the both the short-run and long-run relationship among the instruments are estimated with ARDL-bound test, and the result of the estimations is shown in Table 5 below. Also, results of diagnostic tests ranging from auto and serial correlations to heteroscedasticity are all displayed in Table 5. Firmness of the model is equally tested with cumulative sum and cumulative sum squared (CUSUM and CUSUM^2) tests, and the outputs are placed under Table 5 shown with Figs. 2 and 3. The preliminary test confirmed the goodness of fit of the adopted model with the values of $R^2 = 0.990$ and Adjusted $R^2 = 0.987$. This suggests that the environment indicator (carbon dioxide emission) which is the endogenous instrument (lCO_2) is explained by the exogenous variables (economic growth, urban population, fossil fuels, renewable energy, and FDI) at 99 percent. The remaining part of the carbon emission is explained by the error term. Our model shows ability to correct any short-run disequilibrium in the long run with negative coefficient (−0.112) of the error correction model (ECM) at 1 percent significant level. This points to the correction of the short-run disequilibrium at 11.2 percent in the long run, that is, 8.9 years for the adjustment (1 divided by the coefficient of the ECM). Also, there is a possibility of existence of long-run relationship among the selected variables of this study. Absence of heteroscedasticity and auto and serial correlation is established with the outputs of their respective tests, hence for heteroscedasticity, Breusch-Pagan-Godfrey tests shows F-stats, and Chi-square at 1.220 [0.231] and 43.49 [0.249], and for serial correlation, F-stats, and Chi-square at 0.514 [0.60] and 1.605 [0.45], respectively. Durbin Watson value at 1.8 rules out the presence of autocorrelation from the model. Further check on the stability of the model was done with cumulative sum and cumulative sum square (CUSUM and CUSUM^2), and the output is displayed with Figs. 2 and 3 below Table 5. Lag selection is sensitive in this estimation and hence was performed with Akaike Information Criterion (AIC) and 5 was considered the appropriate lag for this estimation. The result will be available on request. Cointegration was confirmed in this estimation with F-stats from ARDL-bound test greater than the critical values of upper bound at 12.88 and 3.77. Going further in this analysis, we present and explain the findings of dynamic relationships between the instrument

Table 3 Stationarity test (ADF. PP and KPSS)

Variables	@level		@ 1st Diff		
	Intercept	Intercept and trend	Intercept	Intercept and trend	Order
			ADF		
LCO_2	−0.272	−3.786**	−3.324**	−3.311*	MIXED
LY	1.244	−0.891	−2.299	−2.842	MIXED
LU.P	0.396	−2.356	−2.707*	−2.655	I(1)
LFOSS	−0.359	−3.963**	−3.156**	−3.127	MIXED
LR.E	0.486	−3.457**	−2.105	−2.265	I(0)
FDI	−2.781*	−2.974	−2.471	−2.456	I(0)
			PP		
LCO_2	−0.134	−2.580	−4.821***	−4.806***	I(1)
LY	1.702	−0.481	−4.603***	−4.806***	I(1)
LU.P	1.861	−1.970	−3.491***	−3.613**	I(1)
LFOSS	−0.381	−2.538	−4.751***	−4.729***	I(1)
LR.E	1.570	−1.599	−3.902***	−4.149***	I(1)
FDI	−2.122	−2.201	−5.090***	−5.062***	I(1)
			KPSS		
LCO_2	1.254***	0.072	0.048	0.042	I(1)
LY	1.179***	0.283***	0.415*	0.093	MIXED
LU.P	1.266***	0.134*	0.318	0.084	I(1)
LFOSS	1.255***	0.061	0.039	0.039	I(1)
LR.E	1.250***	0.065	0.278	0.087	I(1)
FDI	0.266	0.132*	0.054	0.054	I(1)

Attn: Significant levels are represented with *, **, and *** at 10%, 5%, and 1%, respectively

Source: Authors' computation with Eviews

Table 4 Structural break test (Zivot-Andrew)

Variables	ZA	P-value	Lag	Break period	CV@ 1%	CV@5%
LCO_2	−3.882***	0.008	4	2010Q4	−5.57	−508
LY	−8.085***	0.000	4	1997Q3	−5.57	−508
LU.P	−6.018***	0.000	4	2001Q1	−5.57	−508
LFOSS	−3.622**	0.032	4	2010Q4	−5.57	−508
LR.E	−4.902***	0.007	4	2014Q2	−5.57	−508
FDI	−3.192***	0.003	4	2003Q2	−5.57	−508
$DLCO_2$	−5.531***	0.000	4	2013Q2	−5.57	−508
DLY	−5.596***	0.001	4	1997Q2	−5.57	−508
DLU.P	−9.056***	0.000	4	2000Q2	−5.57	−508
DLFOSS	−5.085***	0.000	4	2013Q2	−5.57	−508
DLR.E	−3.840**	0.050	4	2013Q2	−5.57	−508
DFDI	−5.267***	0.000	4	2000Q2	−5.57	−508

Attn: Significant levels are represented with *, **, and *** at 10%, 5%, and 1%, respectively. *ZA* Zivot Andrew, *LG* lag, *Prob.* probability value, *CV* critical values

Source: Authors' computation with Eviews

in both periods (short-term and long-term estimates). The conclusion and policy recommendation will be majorly built on these findings.

From both short run and long run, we find negative and positive coefficients of LY and LY^2 which established negative connection between economic growth (LY = GDP) and environment (LCO_2) and positive relationship between squared economic growth ($LY^2 = GDP^2$) and environment (LCO_2). Hence, the findings from both short run and long run attest to the U-shaped association between income (GDP) growth and environmental performance. This means that EKC is does not exist in the case of Indonesia. This confirms that CO2 emissions decline at initial level of economic growth and then reaches a turning point and increases with the higher level of economic growth. The U-shaped relationship seems to be apparently generated by country-specific conditions, policy, and technology, and so on. Thus growth impacts on environmental deterioration differ substantially among the high-income economies, whereas among the countries with lower income, growth impacts generated on environment tend to be large. While environmental and income policy is often non-existent for low-income countries, high-income countries have generally introduced varied policies to mitigate the growing environmental degradation. Statistically, a percentage rise in income growth (real GDP) will cause a drop of carbon emissions (LCO_2) by 0.134 percent in both periods. In the case of squared real GDP, coefficient with a positive sign denotes carbon emission increasing as economic growth is increasing confirming a break-out of the initial decreasing relationship at the peak level of income (real GDP). This aligns with the findings of Wijayanti and Sugiyanto (2018) for Indonesia, Hossain (2012) for Japan, Ang (2008) for Malaysia, and Bekhet et al. (2014) for UAE and Saudi Arabia. However, our findings contradict the findings by Sugiawan and Managi (2016) for

Table 5 Cointegration (ARDL-bound test), Short run and Long run linear relationships

Variables	Coef	SE	T-stats
	Short-run		
DLY	−0.134	0.085	−1.566
DLY^2	2.83E-05	1.86E-05	1.519
DLU.P	−2.12E-05	1.76E-06	−12.04***
DLFOSS	3.681	0.086	42.98***
DLR.E	−22.90	5.483	−4.177***
DFDI	−2.165	0.364	−5.952***
CointEq(-1)	−0.112	0.009	−12.04***
	Long-run		
LY	−0.134	0.1371	−0.974
LY^2	2.83E-05	3.00E-05	0.945
LU.P	−2.12E-05	2.42E-06	−8.742***
LFOSS	3.681	0.114	32.34***
LR.E	−22.90	7.327	−3.126***
FDI	−2.165	0.476	−4.549***
C	2.940	0.903	3.258***
R^2	0.990		
Adj R^2	0.987		
D.Watson	1.844		
Wald test	F-stats = 92,917	P–v = 0.000	
Bound-Coint. test	F-stats = 12.88	K = 8,@1%	I(0) = 2.62 I(1) = 3.77
LM serial test	F-stats = 0.514	R^2 = 1.605	[0.60][0.45]
Heteros. test	F-stats = 1.220	R^2 = 43.49	[0.23][0.25]

Attn: *, **, and *** represent significant at 10%, 5%, and 1%, respectively. Numbers inside brackets are the prob. values of F-stats and Chi-square for serial correlation and heteroscedasticity

Source: Authors' computation with Eviews

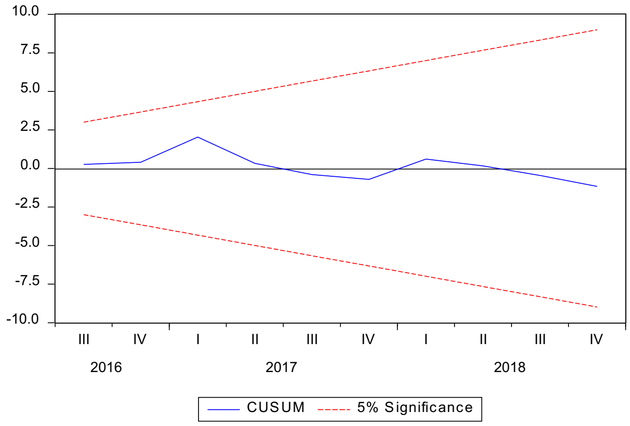

Fig. 2 Test of stability of the model with Cumulative Sum of recursive residual Plot

Indonesia.

Both the short-run and long-run elasticity of carbon emissions (LCO_2) with respect to urbanization (urban population) is – 2.12E-05 (– 0.00000212) for the case of Indonesia. This supposes that a percent increase in urbanization will lead to 2.12E-05 decrease of Indonesia's per capita carbon emission. This is an indication that there is high sensitization and increase awareness of clean in environment in Indonesian cities. It is equally a pointer that literacy rate is high in the country's urban areas. It could equally mean that technological innovation and clean energy mix (renewable energy sources) in economic operations in the cities is at increasing rate. This suggests that carbon neutrality could be attained through urbanization. This finding supports the findings from Ahmed et al. (2019) for Indonesia but contradicts the finding from Kurniawan and Managi (2018). This could be because of difference in indicators of measuring environment in both studies.

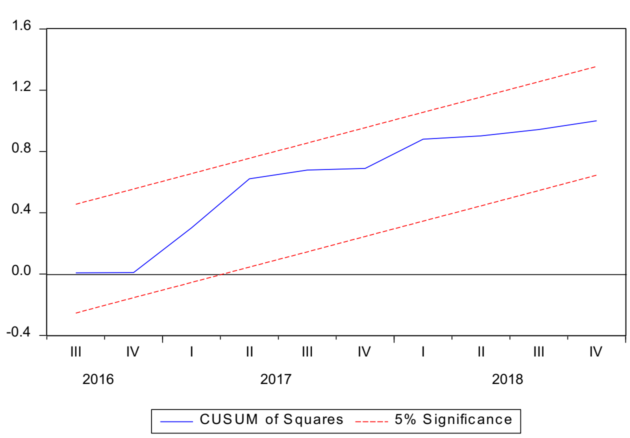

Fig. 3 Test of stability of the model with cumulative sum squared of recursive residual plot

The short-run and long-run elasticity of carbon emission (L CO_2) with respect to non-renewable energy source (fossil fuels) is 3.681, respectively. This shows that a percentage increase in fossil fuels utilization will increase carbon emission by 3.7 percent thereby degrading the Indonesian environmental development. This suggests the negative implication of fossil fuel-based energy consumption on Indonesian environmental development. Many literature (Udemba et al., 2019 for Indonesia; Udemba et al., 2021 for India; Udemba, 2020 for Nigeria; Alola et al., (2021); Alola and Saint Akadiri, (2021)) have found the same result both in the case of Indonesia and other countries.

Going further, we find negative relationships between renewable energy, FDI, and carbon emission. This suggests that both clean energy sources (renewable energy source) and FDI are mitigating the carbon emission increase in Indonesia. This is a good story for Indonesia which points towards carbon neutrality in the country. This shows that foreign investors in Indonesia are operating with consciousness of securing a good environment performance. It equally shows the positive impact of energy transition on Indonesian environment performance. Statistically, both short-run and long-run elasticities of carbon emission with respect to renewable energy and FDI are – 22.90 and – 2.165, respectively. That is, a percentage increase in renewable energy and FDI will decrease carbon emissions by 22.9 and 2.165 percent, respectively. The findings from both renewable energy and FDI for the case of Indonesia are really interesting and are capable of attaining some level of carbon neutrality in the country. This findings support the finding from Udemba et al. (2019) for Indonesia; Haug and Ucal (2019); Sarkodie and Strezov (2019); Shahbaz et al. (2019); and Atici (2012). The entire findings from both ARDL short-run and long-run dynamics point towards carbon neutrality in Indonesia; hence, three instruments (urbanization, FDI, and renewable energy use) adopted in this study point towards their ability to mitigate carbon emission increase in the country. This is a positive trend and a good platform for the policy makers in the country to pursue United Nation's Sustainable Development Goal (SDGs).

Diagnostic tests

CUSUM and CUSUM^2

Granger causality test

Granger causality is adopted in this study to expose the originator and the direction (i.e., uni-directional or bi-directional) of the relationship that existed among the selected variable. It helps to draw inference and in forecasting the future performance trend of the instruments. While the

ARDL dynamics in both short run and long run are exposing the relationship that exists among the variables with the rate of impact, Granger causality gives insight on the instrument that is impacting each other. The result of the pairwise Granger causality is displayed in Table 6 below. From the estimation, we find uni-directional causality passing from economic growth to urbanization, from fossil fuels to urbanization, from renewables to urbanization, from FDI to fossil fuels, and from FDI to renewable energy. Moreover, we find bi-directional causality between urbanization and carbon emission, between renewable energy and carbon emission, and between renewable energy and fossil fuels. The findings from Granger causality give credence to the findings from the ARDL dynamics among the variables in both periods. It gives credence to the above highlighted hypotheses with great exposition on the stance of urbanization, FDI, and renewable energy source in determination of Indonesian environment.

Concluding remark and policy framing

This study attempts to analyze the possibility of accessing carbon neutrality with the nexus of FDI, renewable energy, and urbanization in Indonesia. The objective of the study is to investigate the possibility of Indonesia to mitigate carbon emission with the three policies (FDI, renewable energy, and urbanization) to enhance carbon neutrality of the country. As emerging country that is characterized with growth and investment potentials especially in the areas of gas, electricity, water, and transportation, there is likelihood of great utilization of energy sources which has potentials in impacting environment and climate change through greenhouse gas.

Against this backdrop, we select the macroeconomic and energy cum environment variables (real GDP per capita, FDI, urbanization, fossil fuels, and renewable energy source) to test the sustainable development of the country with respect to environment. We applied

Table 6 Pairwise Granger causality analysis

Null Hypothesis	F-Stat	P-value	Causality	Decision	Direction
Variables					
LGDP→LC0$_2$	0.072	0.789	NO	ACCEPT H_0	NEUTRAL [*LGDP≠LC0$_2$*]
L C0$_2$→LGDP	1.081	0.301			
LU.P→L C0$_2$	2.894	0.092*	YES	REJECT H_0	BI-DIRECTIONAL [*LU.P↔LC0$_2$*]
L C0$_2$→LU.P	4.138	0.044**			
LFOSS→L C0$_2$	1.909	0.164	NO	ACCEPT H_0	NEUTRAL [*LFOSS≠LC0$_2$*]
L C0$_2$→LFOSS	0.501	0.481			
LREN→L C0$_2$	11.72	0.001***	YES	REJECT H_0	BI-DIRECTIONAL [*LREN↔LC0$_2$*]
L C0$_2$→LREN	5.943	0.016**			
FDI→L C0$_2$	1.909	0.170	NO	ACCEPT H_0	NEUTRAL [*FDI≠LC0$_2$*]
L C0$_2$→FDI	0.384	0.537			
LU.P→LGDP	0.270	0.604	YES	REJECT H_0	UNI-DIRECTIONAL [*LGDP→LU.P*]
LGDP→LU.P	5.345	0.023**			
LFOSS→LGDP	0.437	0.510	NO	ACCEPT H_0	NEUTRAL [*LFOSS≠LGDP*]
LGDP→LFOSS	0.002	0.963			
LREN→LGDP	1.211	0.274	NO	ACCEPT H0	NEUTRAL [*LREN≠LGDP*]
LGDP→LREN	2.222	0.138			
LFDI→LGDP	0.536	0.466	NO	ACCEPT H0	NEUTRAL [*FDI≠LGDP*]
LGDP→LFDI	0.015	0.902			
LFOSS→LU.P	3.109	0.081*	YES	REJECT H0	UNI-DIRECTIONAL [*LFOSS→LU.P*]
LU.P→LFOSS	2.164	0.144			
LREN→LU.P	25.36	0.000***	YES	REJECT H0	UNI-DIRECTIONAL [*LREN→LU.P*]
LU.P→LREN	0.300	0.585			
FDI→LU.P	1.614	0.207	NO	ACCEPT H0	NEUTRAL [*FDI≠LU.P]*
LU.P→FDI	0.114	0.736			
LREN→LFOSS	14.58	0.000***	YES	REJECT H0	BI-DIRECTIONAL [*LREN↔LFOSS*]
LFOSS→LREN	6.098	0.015**			
FDI→LFOSS	2.878	0.093*	YES	REJECT H0	UNI-DIRECTIONAL [*FDI→LFOSS*]
L C0$_2$→LGDP	0.371	0.544			
FDI→LREN	14.31	0.000***	YES	REJECT H0	UNI-DIRECTIONAL [*FDI→REN*]
LREN→FDI	0.497	0.482			

The numbers inside bracket are the p-values of the parameters. The numbers that are written in bold colors represent the parameters that are significant in the causal relationship among the variables. Source: Authors' computation different approaches (structural break, ARDL-bound test, and Granger causality) with intent to expose the current state of Indonesian environment performance and its ability to mitigate carbon emission in a bid to foster carbon neutrality. Specifically, we considered the findings from ARDL and Granger causality for this analysis and policy framing. From ARDL short-run and long-run dynamics, we find interesting results pointing towards the ability of Indonesia to mitigate carbon emission (carbon neutrality) except in the case of fossil fuels. Hence, negative relationship is established between carbon emission and renewable energy source, FDI, and urbanization. Also, a U-shape instead of inverted U-shaped EKC is found confirming the impeding implication of Indonesian economic growth to its environmental performance if not checkmate. From Granger causality analysis, all the variables are seen transmitting to urbanization in a one-way causal relationship. Also, FDI and renewable energy prove to be essential determinants of the country's environment development; hence, FDI is seen transmitting to both energy source (fossil fuels and renewables) in a one-way causal relationship, and renewable energy is as well seen having two ways causal relationship with both carbon emission and fossil fuels. This result has equally exposed the significant position of the three instruments (urbanization, FDI, and renewable energy source) in Indonesian environment development, and this finding attests to the above findings from ARDL result.

The expository findings from both approaches are necessary platform for policy enactment towards achieving greater fit in carbon neutrality. Hence, focus should be geared towards sustainable performance of foreign investors. FDI is found impacting positive to the environment development; however, regulatory policies towards safeguarding the quality of the environment from the side of foreign investors should be formulated, implemented, and monitored for maximum achievement and success. National policy should be framed towards energy transition as clean energy source (renewable sources) is seen having the greater percentage of mitigating the carbon emission in the country. Part of the national policies should include bringing the foreign investors to the agreement of adopting improved technologies and adopting cleaner energy sources for the safety of the environment. Also, from the findings, urban populace is contributing towards achieving carbon neutrality but the momentum needs to be preserved through intense awareness on the need to sustain the improved quality of Indonesian environment. Public transportation system should be the top priority in a bid to discourage excessive private vehicles that may constitute environmental harm. Apart from this, efforts should be geared towards shifting from vehicles that run on fossil fuels to electric vehicles to curtail the rate of injecting gases (nitrogen oxide, carbon monoxide, and sulfur dioxide) into the environment. In a nutshell, strong institutions are encouraged in other to achieve effective execution of the proposed policies.

Conclusively, this study has implication to other Southeast Asian countries that may wish to adopt the findings for policy framing for the case of their countries. Again, our work has not close the door of future research into this topic for changes are bound to take place as time goes on, and variance in findings may occur due to structural or natural occurrences. For this, future studies are encouraged especially with other vital instruments such as institutional quality and democracy.

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Author contribution The paper is written by the two authors named in the title page. Hence, Lucy wrote the intro-literature while Edmund wrote the methodology and conclusion with abstract.

Data Availability Data sources are outlined above in Table 1 and will be made available on demand.

Declarations

Ethics approval and consent to participate We the authors are giving our ethical approval and consent for this paper to be published in your Journal if found publishable.

Consent to participate We the authors are giving our consent for participation in this paper to be published in your Journal if found publishable.

Consent for publication We the authors are giving our consent for this paper to be published in your journal if found publishable.

Competing interests The authors declare no competing interests.

References

Abdouli M, Hammami S (2017) Economic growth, FDI inflows and their impact on the environment: an empirical study for the MENA countries. Qual Quant 51(1):121–146

Adedoyin F, Ozturk I, Abubakar I, Kumeka T, Folarin O, Bekun FV (2020) Structural breaks in CO2 emissions: are they caused by climate change protests or other factors? J Environ Manag 266:110628

Ahmad F, Draz MU, Yang SC (2018) Causality nexus of exports, FDI and economic growth of the ASEAN5 economies: evidence from panel data analysis. J Int Trade Econ Dev 27(6):685–700

Ahmed M, Mahmood AN, Hu J (2016) A survey of network anomaly detection techniques. J Netw Comput Appl 60:19–31

Ahmed Z, Wang Z, Ali S (2019) Investigating the non-linear relationship between urbanization and CO 2 emissions: an empirical analysis. Air Qual Atmos Health 12(8):945–953

Ali R, Bakhsh K, Yasin MA (2019) Impact of urbanization on CO2 emissions in emerging economy: evidence from Pakistan. Sustain Cities Soc 48:101553

Alola AA, Saint Akadiri S (2021) Clean energy development in the United States amidst augmented socioeconomic aspects and country-specific policies. Renewable Energy 169:221–230

Alola AA, Lasisi TT, Eluwole KK, Alola UV (2021) Pollutant emission effect of tourism, real income, energy utilization, and urbanization in OECD countries: a panel quantile approach. Environ Sci Pollut Res 28(2):1752–1761

Ang JB (2008) Economic development, pollutant emissions and energy consumption in Malaysia. J Policy Model 30:271–278

Anwar A, Siddique M, Dogan E, Sharif A (2021) The moderating role of renewable and non-renewable energy in environment-income nexus for ASEAN countries: evidence from Method of Moments Quantile Regression. Renewable Energy 164:956–967

Anwar A, Younis M, Ullah I (2020) Impact of urbanization and economic growth on CO2 emission: a case of far east Asian countries. Int J Environ Res Public Health 17(7):2531

Atici C (2012) Carbon emissions, trade liberalization, and the Japan–ASEAN interaction: a group-wise examination. J Jpn Int Econ 26(1):167–178

Aydogan B, O'Neil A, Sahasrabudhe H (2021) Microstructural and mechanical characterization of stainless steel 420 and Inconel 718 multi-material structures fabricated using laser directed energy deposition. J Manuf Process 68:1224–1235

Bachri AA, Normelani E (2020) FDI, income, and environmental pollution in Indonesia. Int J Energy Econ Policy 10(6):383

Balsalobre-Lorente D, Ibáñez-Luzón L, Usman M, Shahbaz M (2022) The environmental Kuznets curve, based on the economic complexity, and the pollution haven hypothesis in PIIGS countries. Renewable Energy 185:1441–1455

Bashir MF, Benjiang MA, Hussain HI, Shahbaz M, Koca K, Shahzadi I (2022) Evaluating environmental commitments to COP21 and the role of economic complexity, renewable energy, financial development, urbanization, and energy innovation: empirical evidence from the RCEP countries. Renewable Energy 184:541–550

Bashir MF, Ma B, Bashir MA, Radulescu M, Shahzad U (2021) Investigating the role of environmental taxes and regulations for renewable energy consumption: evidence from developed economies. Economic Research-Ekonomska Istraživanja, 1–23.

Batool SA, Ahmad H, Gillani SMAH, Raza H, Siddique M, Khan N, Qureshi MI (2021) Investigating the causal linkage among economic growth, energy consumption, urbanization and environmental quality in ASEAN-5 countries. Int J Energy Econ Policy 11(3):319

Bekhet HA, El-Refae G, Yasmin T (2014) Comparative study of environmental Kuznets curve and co-integration between Saudi Arabia and UAE economies: time series analysis.

Canton H (2021) United Nations Conference on Trade and Development—UNCTAD. In The Europa Directory of International Organizations. Routledge, pp 172–176

Dickey DA, Fuller WA (1979) Distribution of the estimators for autoregressive time series with a unit root. J Am Stat Assoc 74(366a):427–431

Dietz T, Rosa EA (1994) Rethinking the environmental impacts of population, affluence and technology. Hum Ecol Rev 1(2):277–300

Effendi N, Soemantri FM (2003) Foreign direct investment and regional economic growth in Indonesia: a panel data study. In The 6TH IRSA INTERNATIONAL CONFERENCE, Regional Development in The Era of Decentralization: Growth, Poverty, and Environment, Bandung.

Ehrlich P, Holdren J (1970) The people problem. Saturday Review 4(42):42–43

Guo M, Hu Y, Yu J (2019) The role of financial development in the process of climate change: evidence from different panel models in China. Atmos Pollut Res 10(5):1375–1382

Harrison P (1994) The third revolution: population, environment and a sustainable world. Can J Dev Stud 15:291

Haug AA, Ucal M (2019) The role of trade and FDI for CO2 emissions in Turkey: nonlinear relationships. Energy Econ 81:297–307

Hossain S (2012) An econometric analysis for CO2 emissions, energy consumption, economic growth, foreign trade and urbanization of Japan. Low Carbon Econ 3:92–105

Huang Y, Haseeb M, Usman M, Ozturk I (2022) Dynamic association between ICT, renewable energy, economic complexity and ecological footprint: is there any difference between E-7 (developing) and G-7 (developed) countries? Technol Soc 68:101853

Hübler M, Keller A (2010) Energy savings via FDI? Empirical evidence from developing countries. Env Dev Econ, 59–80.

Javorcik BS, Spatareanu M (2008) To share or not to share: does local participation matter for spillovers from foreign direct investment? J Dev Econ 85(1–2):194–217

Joshua U, Bekun FV, Sarkodie SA (2020) New insight into the causal linkage between economic expansion, FDI, coal consumption, pollutant emissions and urbanization in South Africa. Environ Sci Pollut Res 27(15):18013–18024

Jun W, Zakaria M, Shahzad SJH, Mahmood H (2018) Effect of FDI on pollution in China: new insights based on wavelet approach. Sustainability 10(11):3859

Katircioglu S (2009) Foreign direct investment and economic growth in Turkey: an empirical investigation by the bounds test for co-integration and causality tests. Econ Res-Ekon Istraž 22(3):1–9

Keller W (2004) International technology diffusion. J Econ Lit 42(3):752–782

Kersan-Škabić I, Zubin C (2009) The influence of foreign direct investment on the growth of GDP, on employment and on export in Croatia. Ekonomski Pregled 60(3–4):119–151

Khaliq A, Noy I (2007) Foreign direct investment and economic growth: empirical evidence from sectoral data in Indonesia. J Econ Lit 45(1):313–325

Kurniawan R, Managi S (2018) Coal consumption, urbanization, and trade openness linkage in Indonesia. Energy Policy 121:576–583

Kusumadewi TV, Limmeechokchai B (2017) CO2 mitigation in residential sector in Indonesia and Thailand: potential of renewable energy and energy efficiency. Energy Procedia 138:955–960

Kuznets S (1955) Economic growth and income inequality. Am Econ Rev 45(1):1–28

Kwiatkowski D, Phillips PC, Schmidt P, Shin Y (1992) Testing the null hypothesis of stationarity against the alternative of a unit root. J Econ 54(1–3):159–178

Merican Y, Yusop Z, Noor ZM, Hook LS (2007) Foreign direct investment and the pollution in five ASEAN nations. Int J Econ Manag 1(2):245–261

Müller F (2017) IRENA as a glocal actor: pathways towards energy governmentality. Innovation: The European Journal of Social Science Research 30(3):306–322

Nathaniel SP (2021) Ecological footprint, energy use, trade, and urbanization linkage in Indonesia. GeoJournal 86(5):2057–2070

Nathaniel SP, Yalciner K, Bekun FV (2021) Assessing the environmental sustainability corridor: linking natural resources, renewable energy, human capital, and ecological footprint in BRICS. Resour Policy 70:101924

Perron P (1990) Testing for a unit root in a time series with a changing mean. J Bus Econ Stat 8(2):153–162

Pesaran MH, Shin Y, Smith RJ (2001) Bounds testing approaches to the analysis of level relationships. J Appl Economet 16(3):289–326

Philip, L. D., Sertoglu, K., Saint Akadiri, S., & Olasehinde-Williams, G. Foreign direct investment amidst global economic downturn: is

there a time-varying implication for environmental sustainability targets?. Environ Sci Pollut Res 1–10.
Qi T, Zhang X, Karplus VJ (2014) The energy and CO2 emissions impact of renewable energy development in China. Energy Policy 68:60–69
Ridzuan NHAM, Marwan NF, Khalid N, Ali MH, Tseng ML (2020) Effects of agriculture, renewable energy, and economic growth on carbon emissions emissions: Evidence of the environmental Kuznets curve. Resour Conserv Recycl 160:104879
Rosa EA, Dietz T (1998) Climate change and society: speculation, construction and scientific investigation. Int Sociol 13(4):421–455
Sarkodie SA, Strezov V (2019) Effect of foreign direct investments, economic development and energy consumption on greenhouse gas emissions in developing countries. Sci Total Environ 646:862–871
Sasana H, Aminata J (2019) Energy subsidy, energy consumption, economic growth, and carbon dioxide emission: Indonesian case studies. Int J Energy Econ Policy 9(2):117
Sasana H, Prakoso JA, Setyaningsih Y (2018) The impact of globalization agains environmental condition in Indonesia. In E3S Web of Conferences. EDP Sciences, vol. 73, p 02012
Sebri M, Ben-Salha O (2014) On the causal dynamics between economic growth, renewable energy consumption, CO2 emissions and trade openness: Fresh evidence from BRICS countries. Renew Sust Energ Rev 39:14–23
Shahbaz M, Balsalobre-Lorente D, Sinha A (2019) Foreign direct Investment–CO2 emissions nexus in Middle East and North African countries: importance of biomass energy consumption. J Clean Prod 217:603–614
Shezan SKA, Das N, Mahmudul H (2017) Techno-economic analysis of a smart-grid hybrid renewable energy system for Brisbane of Australia. Energy Procedia 110:340–345
Sjöholm, F. (2017). Foreign 10 direct investment and value added in Indonesia1. The Indonesian Economy: Trade and Industrial Policies, 238.
Statistics, IEA (2014) Key world energy statistics. Paris International Energy Agency. 2014
Sugiawan Y, Managi S (2016) The environmental Kuznets curve in Indonesia: exploring the potential of renewable energy. Energy Policy 98:187–198
Udemba EN (2019) Triangular nexus between foreign direct investment, international tourism, and energy consumption in the Chinese economy: accounting for environmental quality. Environ Sci Pollut Res 26(24):24819–24830
Udemba EN (2020) A sustainable study of economic growth and development amidst ecological footprint: new insight from Nigerian Perspective. Sci Total Environ 732:139270
Udemba EN, Güngör H, Bekun FV (2019) Environmental implication of offshore economic activities in Indonesia: a dual analyses of cointegration and causality. Environ Sci Pollut Res 26(31):32460–32475
Udemba EN, Güngör H, Bekun FV, Kirikkaleli D (2021) Economic performance of India amidst high CO2 emissions. Sustain Prod Consum 27:52–60
United Nations Conference on Trade and Development (UNCTAD) (2020) World Investment Report 2020. International Production Beyond the Pandemic
Usman M, Balsalobre-Lorente D (2022) Environmental concern in the era of industrialization: can financial development, renewable energy and natural resources alleviate some load? Energy Policy 162:112780
Usman M, Hammar N (2021) Dynamic relationship between technological innovations, financial development, renewable energy, and ecological footprint: fresh insights based on the STIRPAT model for Asia Pacific Economic Cooperation countries. Environ Sci Pollut Res 28(12):15519–15536
Usman M, Makhdum MSA (2021) What abates ecological footprint in BRICS-T region? Exploring the influence of renewable energy, non-renewable energy, agriculture, forest area and financial development. Renewable Energy 179:12–28
Wijayanti DL, Sugiyanto FX (2018) Causality gross domestic product (GDP) and air pollution. An overview of environment Kuznets curve (EKC) case: Indonesia. Adv Sci Lett 24(5):3031–3037
Woodward A, Smith KR, Campbell-Lendrum D, Chadee DD, Honda Y, Liu Q, Haines A (2014) Climate change and health: on the latest IPCC report. The Lancet 383(9924):1185–1189
Yang B, Usman M (2021) Do industrialization, economic growth and globalization processes influence the ecological footprint and healthcare expenditures? Fresh insights based on the STIRPAT model for countries with the highest healthcare expenditures. Sustain Prod Consum 28:893–910
Yanga QW, Weib H, Lic Z (2021) Enhancing water evaporation by combining dynamic and static treatment of magnetic field. Desalination and Water Treatment 216:299–305
York R, Rosa EA, Dietz T (2003a) Footprints on the earth: the environmental consequences of modernity. Am Sociol Rev 68:279–300
York R, Rosa EA, Dietz T (2003b) STIRPAT, IPAT and ImPACT: analytic tools for unpacking the driving forces of environmental impacts. Ecol Econ 46(3):351–365
Zhang S, Zhao T (2019) Identifying major influencing factors of CO2 emissions in China: regional disparities analysis based on STIRPAT model from 1996 to 2015. Atmos Environ 207:136–147
Zivot EA, Andrews DWK (1992) Further evidence on the great crash, oil prices shock and the unit root hypothesis. J Bus Econ Stat 10(3):251–270