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RESEARCH ARTICLE

Investigating the Environmental Kuznets Curve hypothesis amidst geopolitical risk: Global evidence using bootstrap ARDL approach

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Abstract

Environmental concerns have become one of the top inevitable issues the world has been facing nowadays. Human-induced carbon emissions are the main reasons behind these environmental issues and to reduce them and mitigate their consequences, policymakers globally explore their drivers and determinants continuously. Although several socio-economic factors have been explored that affect the level of emissions, relatively less attention has been paid to geopolitical risk (GPR). Over the past few decades, the world has witnessed a significant rise in GPR with economic and environmental impacts. However, the existing body of literature on the GPR-environment nexus documents the contrasting conclusion, which might cause inconvenience while proposing environmental protection policies. Therefore, the present study reinvestigates the impact of GPR on carbon emissions at the global level. The findings document that, in the short run, a 1% rise in GPR impedes emissions by 3.50% globally. On the contrary, a 13.24% rise in emissions is fostered by a 1% increase in GPR in the long run. Also as was expected, we report that energy consumption leads to higher global emissions in both the short and long run. Next, this study also validates the existence of the environmental Kuznets curve (EKC) hypothesis at the global level. Based on these aforementioned outcomes, we propose several policy recommendations to curb global carbon emissions via GPR accomplish, thus, a few sustainable development goals.

Keywords Geopolitical risk · CO_2 emissions · Economic growth · Energy consumption · Bootstrap ARDL · Sustainable development goals

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Introduction

During the last two decades, one of the most repeatedly and globally recognized burning issues is considered to be environmental degradation with its associated detrimental impacts on human health, ecosystem, and economic activities (e.g., production and consumption activities). Next, CO_2 emission (i.e., a critical greenhouse gas) is regarded as one of the key reasons behind the aforementioned environmental issues. According to Carbon Dioxide Information Analysis Center (2014), global CO_2 emissions surged from 4053 million metric tons in 1970 to 9855 million metric tons in 2014. This indicates that global CO_2 emissions have increased almost 143% from 1970 to 2014. Given the high growth rate of emissions, as well as its current and projected levels, policymakers have been making efforts to mitigate emissions via policies at the national level but even more importantly, through intergovernmental and international commitments such as the Kyoto Protocol and the Paris Agreement.

However, the levels of emissions have not shown drastic changes and hence more focus is required for promoting future sustainability.

There exists a plethora of empirical literature that explores the drivers of CO_2 emissions. Nevertheless, the most inevitable determinants of CO_2 emissions are economic growth and energy consumption (Antonakakis et al., 2017; Bekun et al., 2019a, 2019b; Zhang et al., 2019; Adedoyin et al., 2021a). Moreover, past literature highlights several socio-economic indicators as key drivers of CO_2 emissions, namely trade (Halicioglu, 2009; Shahbaz et al., 2013; Chen et al., 2019; Haug and Ucal, 2019), financial development (Abbasi and Riaz, 2016; Dogan and Turkekul, 2016; Bekhet et al., 2017; Shoaib et al., 2020), urbanization (Zhu et al., 2012; Sadorsky, 2014; Shahbaz et al., 2016; Ali et al., 2019), natural resources (Bekun et al., 2019a, 2019b; Danish et al., 2019; Khan et al., 2020; Shittu et al., 2021), economic policy uncertainty (Jiang et al., 2019a; Adedoyin & Zakari, 2020; Adedoyin et al., 2020a) globalization (Zaidi et al., 2019), economic structure (Dogan and Inglesi-Lotz, 2020), foreign direct investment (Bulut et al., 2021), R&D (Adedoyin et al., 2020b), coal rent (Adedoyin et al., 2020c), economic complexity (Adedoyin et al., 2021b, 2021c), unemployment (Roni et al., 2021), and tourism (Zhang & Zhang, 2018a, 2018b; Balli et al., 2019; Selvanathan et al. 2020).

Nonetheless, the impact of geopolitical risk (GPR) on CO_2 emissions remains understudied. GPR, which is uncertainty associated with war, terrorism, and political tensions, has economic impacts (Caldara and Iacoviello, 2018). Thus, GPR can potentially affect environmental degradation as well (Adams et al., 2020). The literature has paid little to no attention to the role of geopolitical risk (GPR) on emissions internationally. Based on the prior literature on GPR-emissions nexus, GPR can either surge or impede carbon emissions (Anser et al., 2021a, 2021b; Zhao et al., 2021). Parallel to this, Akadiri et al. (2020) noted that GPR has detrimental impacts on economic growth, on the contrary, several studies (see, e.g., Bekun et al., 2019a, 2019b) reveal that economic growth leads to environmental degradation through high carbon emissions. Hence, it could be possible that GPR leads to higher carbon emissions. Likewise, Wang et al. (2018) reported that GPR plunges firm-level investment; parallel to this, many research outlets note that investment affects carbon emissions (see, for example, Blanco et al., 2013; Xie et al., 2020). So, GPR could affect CO2 emissions through investment. Alsagr and Hemmen (2021) reveal that GPR escalates renewable energy consumption in emerging economies. However, Zhao et al. (2021) reported that any shock in GPR impedes non-renewable energy consumption in a few BRICS countries. In addition, Sweidan (2021) reports that GPR ameliorates the renewable energy deployment in the case of the USA. Therefore, it is indispensable to explore the nexus between GPR and CO_2 emissions.

The outcomes and findings of the literature have not reached a consensus on the nexus between GPR and carbon emissions. For instance, by using panel ARDL methodology, Adams et al. (2020) concluded that GPR in resource-rich countries has an adverse impact on carbon emissions, implying that the GPR ameliorates the environmental quality. Similarly, Anser et al. (2021b) employed AMG estimators to explore the impact of GPR on the ecological footprint in the case of BRMCC (i.e., Brazil, Russia, Mexico, China, and Colombia) countries. The study notes that GPR impedes ecological footprint in selected countries. On the contrary, Anser et al. (2021a) employ AMG estimators to discern the impact of GPR on carbon emissions in the case of BRICS countries. The findings from the study reveal that GPR leads to higher emissions. Besides, Zhao et al. (2021) employ NARDL (nonlinear ARDL) model, and highlight that there exists an asymmetric impact of GPR on carbon emissions in the case of BRICS countries, and under which conditions. The lack of consensus in the literature might be attributed to the variety of periods and methodologies, and focus on geographical areas—and that strengthens the motivation for this study's choice to examine the relationship at a global level.

In this paper, we advocate the globality of CO2 emissions and their consequences that is and should be a worldwide concern regardless of geographical boundaries. Thus, this study aims at investigating the impact of GPR on CO2 emissions at the global level for the period 1970–2015. The present study adds to the existing literature of environmental economics in several dimensions. Firstly, given our best knowledge on this issue, such a global analysis has not yet been conducted to explore the nexus between GPR and CO_2 emissions. Second, previous studies that examine the validity of the EKC hypothesis at the global level do not use the global income & level of emissions, rather they just collect the data on a large number of countries to proxied global income and emissions (see, for example, Chang and Hao, 2017; Gulistan et al., 2020), which may lead to unreliable findings. To overcome this issue, the present study makes use of data on global GDP and global carbon emissions to test the validity of the EKC hypothesis (at the world level) for the first time in the literature. Further, the study contributes to the growing literature of studies using the environmental Kuznets curve (EKC) theoretical hypothesis by expanding it to take into consideration the GPR. Next, the study employs the methodology of bootstrap ARDL proposed by McNown et al. (2018) for robust and reliable outcomes. It is worth noting that the bootstrap ARDL approach uses an additional *F*-test to render a complete picture of co-integration among selected variables; thus, it outperforms other ARDL models (e.g., ARDL, NARDL, and QARDL) in terms of size and power properties.

Literature review

This section notes several socio-economic determinants of CO_2 emissions. As climate change and global warming are increasing concerns across the world, a substantial number of researchers have analyzed them along with different influential factors impelling carbon emissions (Richmond and Kaufmann, 2006; Katircioğlu and Taşpinar, 2017; Mutascu, 2018; Jiang et al., 2019b). In the economy-environment nexus, the environmental Kuznets curve (EKC) hypothesis has been a prime conjecture (Dogan and Turkekul, 2016; Pata, 2018; Işık et al., 2019), which implies the presence of an inverted U-shaped relationship between income and environmental degradation. Researchers have been investigating the validity of the EKC hypothesis over the last decades and have generated mixed and contrasting results. One group report that an inverted U-shaped relationship between income and environment does exist (Tang and Tan, 2015; Bilgili et al., 2016; Kacprzyk and Kuchta, 2020), while the other group claims that the presence of an N-shaped relationship is valid (Lee and Oh, 2015; Allard et al., 2018). Several other studies expound on the U-shaped and roughly M-shaped relationship between income and environment quality (Sinha et al., 2017; Minlah and Zhang, 2021). It is worth mentioning that models and methods, time, countries, and the choice of control variables are mainly responsible for the mixed findings in the context of the EKC hypothesis (Heidari et al., 2015; Jamel and Maktouf, 2017; Pata, 2018).

Similarly, there are a few other studies that link (un) employment with the environment. More specifically, Witzke and Urfei (2001) examine the determinants of the willingness to pay for environmental issues, and they find the employment status is explicitly considered as one of those determinants. Likewise, Veisten et al. (2004) reported that unemployment impedes the willingness to pay for high environmental quality. In contrast, there exists some empirical evidence which notes that the employment status and willingness to pay for environmental issues do not have any relationship between them (Torgler and García-Valiñas, 2007; Ferreira and Moro, 2013; De Silva and Pownall, 2014). Recently, Kashem and Rahman (2020) put forward the Environmental Phillips curve (EPC) hypothesis, i.e., the presence of a negative relationship between unemployment and environmental quality. Additionally, Joshua and Alola (2020) examine the role of employment within the pollution haven hypothesis for the case of South Africa. They provide evidence that employment leads to high carbon emissions. Similarly, Gyamfi et al. (2020) use the EKC framework to investigate the relationship between employment and the environment. The findings from this study document that rises in employment contribute to high carbon emissions. Next, Anser et al. (2021a) support the validity of EPC for the case of BRICST countries, and also report that economic growth and energy consumption escalate environmental degradation. In contrast, our study probes the impact of uncertainty related to economic policies within the EPC framework, whilst employing the novel dynamic ARDL simulations approach. In other words, our study extends the EPC literature in certain dimensions.

Parallel to this, energy consumption is often cited as one of the eminent drivers of CO_2 emissions (Saboori et al., 2014). The use of crude oil, natural gas, and coal emits high levels of CO_2 emissions (Destek and Sinha, 2020; Haug and Ucal, 2019). Several works also highlight the direction of causality between energy and the environment (Zhang and Lin, 2012; Nathaniel and Iheonu, 2019). Moreover, one strand of the literature disaggregates energy into renewable and non-renewable energy and notes that these two energy sources have a heterogeneous impact on CO_2 emissions (Sadorsky, 2014). Likewise, energy efficiency (i.e., the productivity of energy consumption) plunges CO_2 emissions, since the same amount of energy can produce higher output (Afionis et al., 2017). Higher energy prices also can reduce the demand for energy, which eventually mitigates CO_2 emissions (Joo et al., 2015; Dogan and Turkekul, 2016).

Foreign direct investment (FDI) can either upsurge or impede CO_2 emissions. According to the pollution haven hypothesis, FDI could bring in environmentally unfriendly technologies. As a result, the levels of CO_2 emissions can significantly increase (Khavarian et al., 2019; Destek and Sinha, 2020). In contrast, the pollution haven hypothesis notes that FDI encourages environment-friendly technologies, and ultimately reduces CO_2 emissions (Belke et al., 2011; Jiang et al., 2019b). The environmental impact of trade is also unclear because a strand of the literature argues that trade escalates environmental quality, while others report that the opposite holds (Chen et al., 2019). More specifically, the trade-environment nexus depends on the nature of goods and services traded, as well as on the direction of the trade (Halicioglu, 2009; Zhao et al., 2018).

Besides, several studies explore socio-economic drives of carbon emissions such as natural resources (Bekun et al., 2019a, 2019b; Danish et al., 2019), urbanization (Sadorsky, 2014; Ali et al., 2019), and tourism (Dietz and Rosa, 1997). It is worth reporting that these aforementioned indicators can either increase or plunge carbon emissions. Next, political, social, and economic globalization can also affect consumption and production decisions, and ultimately hit CO_2 emissions (Bilgili et al., 2016; Zaidi et al., 2019). The empirical literature also reports that political instability affects various economic decisions, and in turn, CO_2 emissions (Wang et al., 2018; Mahalik et al., 2021). Additionally, corruption, terrorism, and militarization can determine the levels of CO_2 emissions (Bildirici and Gokmenoglu, 2020), while monetary, fiscal, and trade policies can also have direct, as well as indirect, impacts on CO_2 emissions (Halicioglu, 2009; Dogan and Turkekul, 2016). Finally, a few other research outlets also show that there exists an asymmetric impact of economic policies on CO_2 emissions (Danish et al., 2019).

The expansion of R&D investment, innovations, and technological advancements could improve energy efficiency, with these factors being able to put forward new methods to utilize renewable energy. As a result, CO_2 emissions are expected to get significantly plunged (Garrone and Grilli, 2010; Zhang and Zhang, 2018a, 2018b). Furthermore, financial development can also promote green investments, which reduce CO_2 emissions. By contrast, there exist a few empirical studies which report that financial development upsurges energy consumption and economic growth, therefore, escalating the levels of CO_2 emissions (Shahbaz et al., 2013; Bekhet et al., 2017; Shoaib et al., 2020).

It is worth noting that GPR affects several socio-economic indicators that have been reported in the past literature. For instance, Akadiri et al. (2020) find that GPR impedes both economic growth and tourism in Turkey. Likewise, Ghosh (2021) reveal that GPR has a detrimental impact on tourism in the case of India. Next, Dogan et al. (2021) reveal that GPR mitigates the natural resource rents in developing economies. Further, Rasoulinezhad et al. (2020) conclude that GPR escalates the energy transition in the case of Russia. In addition, Olanipekun and Alola (2020) report that GPR mitigates oil production in the short run. Parallel to this, Pan (2019) reveals that GPR hinders the investment in R&D at the firm level.

Parallel to this, there exists a scarcity of literature that links GPR with CO_2 emissions. The study of Adams et al. (2020) is one of the seminal studies that examine the impact of GPR on carbon emissions. The findings from the PMG-ARDL approach reveal that GPR mitigates carbon emissions in top resource-rich economies. Next, using AMG estimators, Anser et al. (2021b) report that GPR impedes emissions in the case of selected emerging economies. On the contrary, using AMG estimators, Anser et al. (2021a) note that GPR upsurges carbon emissions in the case of BRICS countries. Using the NARDL approach, Zhao et al. (2021) note that GPR has an asymmetric impact on CO_2 emissions in the case of BRICS countries. Based on the above discussion, it could be noted that the relationship between GPR and emissions has been explored solely in emerging economies, and there is the likelihood of different findings in the case of other countries (e.g., developed countries or least developed countries). Also, there exists no study that renders global evidence on GPR-emissions nexus. Next, the prior studies on GPR-emissions nexus have contrasting outcomes that call for reinvestigating the aforementioned nexus for clear and/or certain results. This motivates the present study to reinvestigate the GPR-emissions nexus at the global level.

Theoretical background

The focus of this section is to provide theoretical arguments that link GPR with CO_2 emissions. It is well known that GPR affects several socio-economic indicators such as economic growth (Akadiri et al., 2020), energy consumption (Sweidan, 2021), trade (Gupta et al., 2019), investment (Le and Tran, 2021), oil prices (Cunado et al., 2020), tourism (Akadiri et al., 2020), the stock market (Yang and Yang, 2021), and R&D (Pan, 2019). Parallel to this, a plethora of literature in environmental economics notes that these aforementioned indicators (i.e., economic growth, energy, trade, investment, oil prices, tourism, and the stock market) affect carbon emissions (Adedoyin et al., 2021a, 2021b; Zhao et al., 2018; Zhang and Zhang, 2018a, 2018b). Hence, we can believe that GPR affects emissions through these socio-economic indicators.

Recently, Anser et al. (2021b) present two theoretical channels/effects that explain how GPR affects environmental degradation. The "mitigating effect" argues that GPR lowers the level of emissions through lower energy consumption and economic growth. However, the "escalating effect" notes that GPR increases emissions through a low level of R&D, innovations, and green investment. We depict these two channels/effects in Fig. 1.

Data and methods

Data

The current study makes use of annual data spanning the period 1970–2015. The key independent variable is the Geopolitical Risk Index[1] developed by Caldara and Iacoviello (2018). It is worth mentioning that the GPR index is calculated through the frequency of newspaper articles containing words related to geopolitical risk. Moreover, data on the GPR index are gathered from http://policyuncertainty.com.

On the contrary, the dependent variable of this study is global carbon dioxide emissions (CO_2), measured in metric tons. Also, the data on global CO_2 emissions are obtained from a database of Carbon Dioxide Information Analysis Center. Moreover, we use world/global GDP (GGDP) and world/global energy consumption (GEN) as control variables. The data on GGDP and GEN are gathered from the

[1] We use geopolitical risk historical index (GPRH) as proxy for global geopolitical risk Fig. 2.

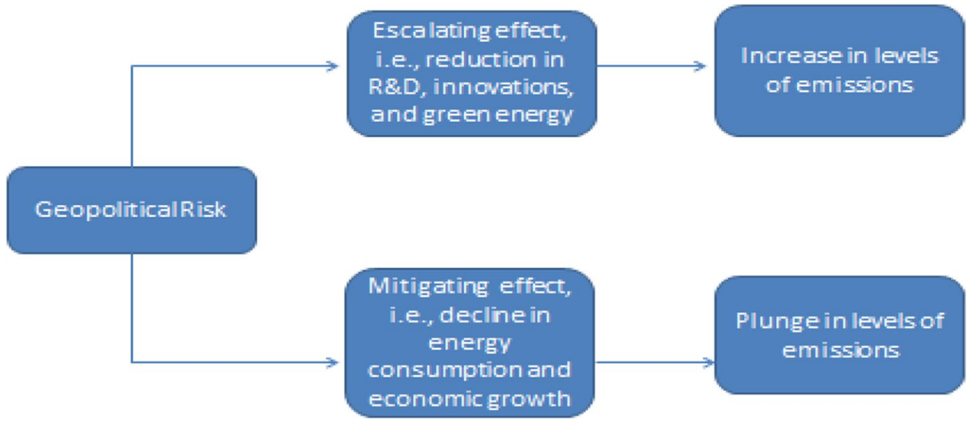

Fig. 1 Theoretical link between GPR and CO2 emissions

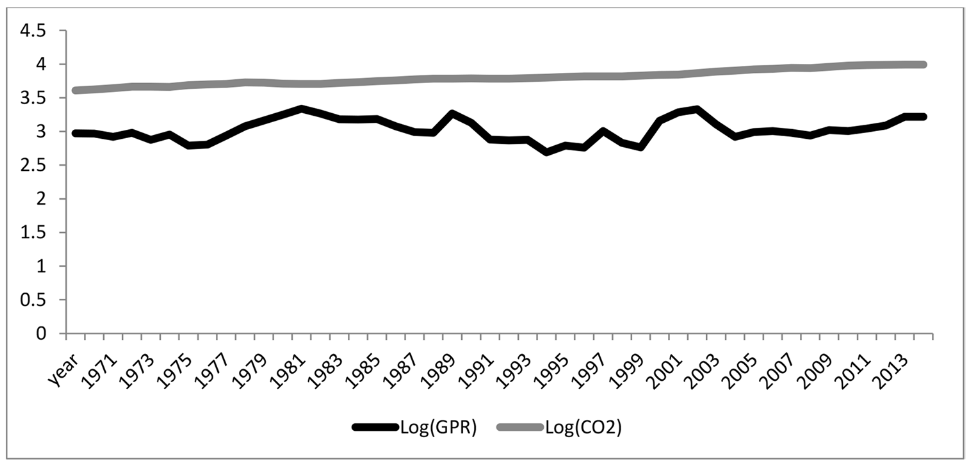

Fig. 2 Trend of GPR and CO2 emissions. Source: authors' calculation

Table 1 Summary of variables

Name	Symbol	Scale	Source
World carbon dioxide emissions	CO_2	Metric ton	https://ourworldindata.org
Geopolitical risk index	GPR	Frequency of articles with words/terms related to geopolitical risk	http://policyuncertainty.com
World gross domestic product	GGDP	2011 US dollar value	https://ourworldindata.org
World energy consumption	GEN	Terawatt-hour (TWh)	https://ourworldindata.org

World Bank database. Table 1 elaborates the description of selected variables.

Next, all selected variables are transformed into logarithmic form to avoid the issue of heteroscedasticity and interpret the coefficients as elasticities (Anser et al., 2021b). Also, Table 2 reports the descriptive statistics and correlation that show the following information. The average (mean) value of GEN is the highest, whilst the standard deviation of GPR is the highest. Next, all variables of this study are positively skewed and do not have thick tails. Next, findings from the Jarque–Bera test reveal that selected variables are following a normal distribution. Further, correlation is the strongest between GEN and carbon emissions, while it is the lowest between GGDP and GPR.

Model

In the literature of environmental economics, several econometric/empirical models have been applied. However, a critical model/framework/hypothesis is environmental Kuznets curve (EKC) framework that expounds the inverted U-shaped relationship between income and environment. This study employs the EKC framework introduced by Narayan and Narayan (2010) that examines inverted U-shaped relationships based on

Table 2 Descriptive statistics

Statistic	GPR	CO_2	GGDP	GEN
Mean	3.02	0.16	0.57	4.59
St. deviation	0.28	0.10	0.01	0.07
Skewness	0.75	0.39	0.23	0.64
Kurtosis	0.15	0.07	0.17	0.14
Jarque–Bera	(0.32)	(0.12)	(0.17)	(0.29)
Correlation				
	CO_2	GGDP	GEN	GPR
CO_2	1.00			
GGDP	0.96	1.00		
GEN	0.99	0.95	1.00	
GPR	0.11	0.10	0.15	1.00

Values in parentheses represent *p*-value. A triple asterisk denotes significance level at 1%

short- and long-run income elasticity. There exist a plethora of studies that employ the EKC model by Narayan and Narayan (2010) to investigate the socio-economic determinants of CO_2 emissions (see, inter alia, Al-Mulali et al., 2015; Shahbaz et al., 2016; Sinha and Shahbaz, 2017). Next, we use energy consumption as a control variable to avoid the issue of omitted variable bias. It is worth reporting that Danish et al. (2020) employ the same model (i.e., employing the EKC framework of Narayan and Narayan (2010) in consort with energy consumption as a control variable) to analyze the impact of economic policy uncertainty amidst the energy-emissions nexus. Hence, we borrow the model from the study of Danish et al. (2020), and the final model yields:

$$CO_2 = f(\text{GPR},\ \text{GGDP},\ \text{GEN}) \quad (1)$$

In Eq. (1), CO_2 denotes carbon dioxide emissions, GPR represents geopolitical risk index, GGDP is global/world GDP, and GEN denotes global energy consumption. Regarding the choice of control variables, the lack of data availability on other critical variables (e.g., urbanization, FDI, trade, and financial development) at the global level for the selected period restrain this study to solely employ energy consumption. It is worth noting that energy consumption is among the most indispensable drivers of carbon emissions. Fossil fuels consist of high carbon-based sources of energy, and when burnt, emit high levels of carbon emissions. Based on the unavoidable importance of energy consumption as a driver of emissions, several studies include it as a control variable (see, for example, Adedoyin et al., 2020a, 2020b).

Methodology

Since this study makes use of time series data, we conduct a few preliminary tests before employing the bootstrap ARDL approach. It is worth reporting that unit root is one of the most common issues in time series data that can lead to spurious regression/results. Also, the bootstrap ARDL approach requires the dataset with an order of integration not more than I (1). Therefore, this study employs the ADF and Zivot and Andrews unit root test to probe the unit root (order of integration) properties.

To test the long-run relationship (co-integration) among variables, Pesaran et al. (2001) put forward the ARDL bounds test. It is worth mentioning that the ARDL bounds test outperforms other approaches (e.g., Engle and Granger (1987) and Johansen (1988)) because it can be applied if variables have mixed order of integration. Based on the ARDL approach, Eq. (1) can be reported as follows:

$$\Delta CO_2 = \alpha + BD + \sum_{i=1}^{p} \beta_i \Delta CO_{2_{t-i}} + \sum_{i=1}^{q} \gamma_i \Delta GPR_{t-i} + \sum_{i=1}^{m} \omega_i \Delta GGDP_{t-i} + \sum_{i=1}^{n} \psi_i \Delta GEN_{t-i} + \pi_1 CO_{2_{t-1}} + \pi_2 GPR_{t-1} + \pi_3 GGDP_{t-1} + \pi_4 GEN_{t-1} + \varepsilon_t \quad (2)$$

Equation (2) is case III of the ARDL approach, which is no trend with unrestricted constant (intercept). In Eq. (2), α is intercept, whilst *BD* is the break date. In addition, β_i, γ_i, ω_i, and ψ_i represent short-run coefficient, whereas π_i (i = 1, 2, 3, 4) is the long-run coefficient. Next, *p*, *q*, *m*, and *n* represent lag order. Finally, ε_t denotes error term.

One of the assumptions of the ARDL bounds test is that the dependent variable does not affect the independent variable(s), meaning that variables are (weakly) exogenous. Nevertheless, this assumption is rarely fulfilled in real data. Hence, if the exogeneity assumption violates, the assumption regarding the distribution of the ARDL bounds test will not be fulfilled (McNnown et al., 2018).

To report the existence of long-run relationship amongst variables, Pesaran et al. (2001) proposed two tests: *F*-test (Ho:$\pi_1 = \pi_2 = \pi_3 = \pi_4 = 0$) on all lagged level variables (i.e., all long-run coefficients), and *t*-test (Ho: $\pi_1 = 0$) on lagged level dependent variable. Nonetheless, McNown et al. (2018) put forward an additional *F*-test on lagged level independent variables (Ho:$\pi_2 = \pi_3 = \pi_4 = 0$) in bootstrap ARDL approach, which is complementary to the aforementioned *F*-test and *t*-test of Pesaran et al. (2001). McNown et al. (2018) argue that these three tests should be applied to distinguish between co-integration, non-co-integration, and degenerate cases. There exist 2 degenerate cases, and both of them imply that is no co-integration among variables. Degenerate case I arise when lagged level dependent variable is statistically insignificant, whilst degenerate case II is observed when lagged level independent variable(s) becomes statistically insignificant.

It is worth noting that critical values for degenerate case II are provided by Pesaran et al. (2001), whereas critical values for degenerate case I are not rendered. In order to rule out the degenerate case I, the dependent variable must be stationary at I (1). Nevertheless, it is known that unit root tests have low power, implying that the findings from the unit root test could be misleading. So, the bootstrap ARDL test covers this issue by providing an additional *F*-test on lagged level independent variables. Thus, bootstrap ARDL notes that co-integration will be investigated based on all three tests reported as follows:

F-test (overall): On all lagged level variables;

t-test (dep): On lagged level dependent variable; and.

F-test (indep): On lagged level independent variables.

Next, co-integration exists if and only if the null hypothesis of these aforementioned tests will be rejected. Thus, the bootstrap ARDL approach outperforms conventional ARDL bounds tests because it renders a complete picture of co-integration and rules out the inconclusive findings. Based on the advantages of the bootstrap ARDL approach, this study employs this novel methodology to explore the impact of geopolitical risk on global carbon emissions.

Empirical findings

To provide reliable and robust outcomes, this study follows the procedure depicted in Fig. 3.

To employ the bootstrap ARDL approach, it is necessary to examine the stationary properties of selected variables. Therefore, we apply the ADF unit root test and Zivot and Andrews (1992) test (ZA hereafter). The advantage of ZA test is its ability to cover the structural break in the dataset, which motivates this study to apply it along with the ADF test. The findings from both unit root tests are reported in Table 3.

As can be seen from Table 3, using the ADF test and ZA test, we could not reject the null hypothesis of no unit root at I (0). This implies that all selected variables are non-stationary at I (0). On the contrary, the null hypothesis could be rejected at I (1) based on the findings of both the ADF test and ZA test. Thus, all selected variables of this study are integrated at I (1).

Next, we employ novel bootstrap ARDL approach to investigate the impact of GPR on global carbon emissions. In this regard, Table 4 reports the co-integration results. The co-integration analysis can be seen in Table 4, where the findings from all three tests are reported. The calculated values of *F*-test (overall), *t*-test (dep.), and *F*-test (indep.) are higher than the upper bounds values. This indicates that the null hypothesis of non-co-integration could be rejected at a 1% level of significance. Thus, we report the occurrence of co-integration among the selected variables of the present study.

Further, Table 5 depicts the short- and long-run estimates from the bootstrap ARDL approach coupled with the diagnostics. We set maximum lags at 4, whereas AIC is chosen for optimum lag selection. Regarding the short-run results, reported in panel I, the value of the coefficient of GPR is −3.50, which is also statistically significant at 1%. This indicates that ceteris paribus, a 3.50% plunge in global carbon emissions is fostered by a 1% increase in geopolitical risk. Therefore, it could be concluded that geopolitical risk impedes global emissions, which, in turn, ameliorates environmental quality. Hence, we report that the magnitude of the mitigating effect is higher than that of escalating effect. This notes that GPR mitigates production activities and

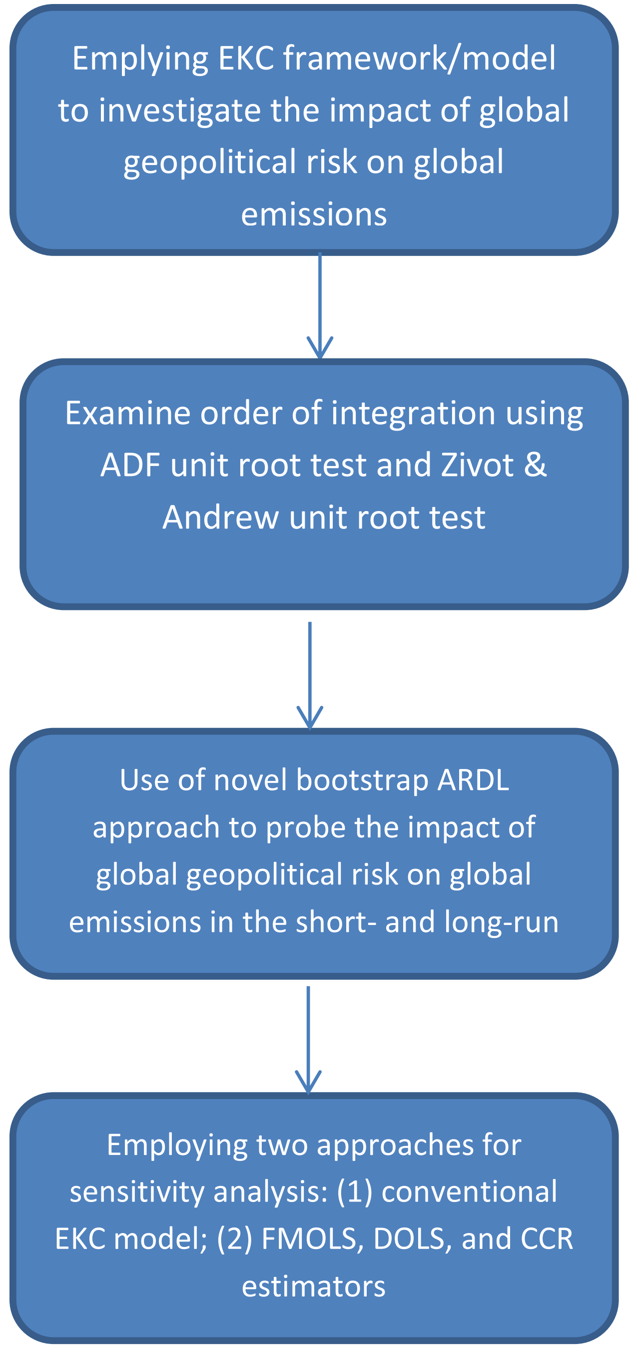

Fig. 3 Route of methods/procedure followed by this study

Table 3 Unit root tests

	ADF test	ZA test		
	I (0)	I (1)	I (0)	I (1)
CO_2	(0.11)	(0.00)***	−2.12 [2008]	−5.98*** [2009]
GPR	(0.16)	(0.00)***	−3.01 [2001]	−5.72*** [2001]
GGDP	(0.21)	(0.00)***	−2.87 [2007]	−6.01*** [2008]
GEN	(0.10)	(0.00)***	−3.09 [2008]	−5.82*** [1970]

Values in parentheses are the *p* value, and triple asterisks represent the level of significance at 1%. Next, values within brackets denote break date

Table 4 Summary of co-integration

Test	Calculated value	I (0)	I (1)
F-test (overall)	6.28	3.74	5.06
t-test (dep.)	−4.90	-3.43	−4.60
F-test (indep.)	7.09	4.34	7.06

The critical values of the *F*-test (indep.) are taken from Sam et al. (2019) at $k=3$ and $n=45$

Table 5 Findings from bootstrap ARDL (2, 4, 2, 3) approach

Indicator	Value	Probability value
Short-run estimates (panel I)		
ΔGPR_t	−3.50	0.00***
ΔGPR_{t-1}	−2.13	0.00***
ΔGEN_t	0.76	0.00***
$\Delta GGDP_t$	2.89	0.00***
Long-run estimates (panel II)		
GPR_{t-1}	13.24	0.03**
$GGDP_{t-1}$	1.26	0.02***
GEN_{t-1}	10.65	0.02***
CO_{2t-1}	−0.45	0.10
Diagnostics (panel III)		
R^2 (adjusted)	0.78	
Ramsey RESET test	(0.51)	
LM test	(0.29)	
CUSUM test	Stable	
$CUSUM^2$ test	Stable	
Jarque–Bera test	(0.17)	
ARCH test	(0.29)	
ECT	−0.19***	

Single, double, and triple asterisks denote level of significance at 1%, 5%, and 10%, respectively. Although the bootstrap ARDL (2, 4, 2, 3) model has been chosen, we just report the significant coefficients

energy consumption. As a result, global carbon emissions will be decreased. These findings are in line with the results of Adams et al. (2020) and Anser et al. (2021b). Moreover, the first lag of GPR is also statistically significant, and it has a negative value. This reports that current geopolitical risk mitigates future carbon emissions. It has been observed that during the episodes of high geopolitical tensions, levels of emissions were plunged. For instance, in the short run, the events like Gulf War, the Iraq-US war, Arab Spring, and ISIS attacks affected the energy consumption in consort with the industrial production. As a result, emissions drastically plunged.

Next, the coefficient of GGDP is positive and statistically significant. The value of GGDP is 2.89, indicating that a 1% upsurge in global GDP growth (i.e., global economic growth) escalates the global carbon emissions by 2.89%. Hence, it could be inferred that global economic growth deteriorates the environmental quality in the short run. These findings are backed by the conclusion of Adebayo et al. (2021). Next, the coefficient of GEN is positive and statistically significant. The value of GEN is 0.76, reporting that a 1% increase in global energy consumption leads to higher global emissions by 0.76%. These findings are in line with the results of Agabo et al. (2021).

Similarly, panel II shows the long-run results. The value of GPR is 13.24 that is statistically significant. This expounds that a 13.24% increase in global carbon emissions is fostered by a 1% upsurge in geopolitical risk, ceteris paribus. Hence, we note that, in the long run, the mitigating effect is lower than the escalating effect. That is, GPR impedes R&D, green investment, technological advancement, and innovations. As a result, global carbon emissions will surge. This conclusion is backed by the findings of Anser et al. (2021a). The world has witnessed the fact that geopolitical tensions such as the 9/11 attacks, the US-China trade war, and India-China border conflicts affect global stock markets, R&D investment, research grants, and expenditure on innovations, which, in turn, escalates the levels of emissions. Moreover, the high global geopolitical tensions compelled producers to keep using the traditional energy-inefficient technologies and hence carbon emissions escalated.

The coefficient of CO2 is statistically insignificant, suggesting that global carbon emissions in past do not affect current global carbon emissions. Such a finding gives a note of hope for the future as the emissions at a global level might be proven to reduce by changing various other determinants. Moreover, the value of GGDP is 1.26, and it is statistically significant. This notes that ceteris paribus, a 1% increase in global economic growth leads to higher global carbon emissions by 1.26%. It is worth reporting that the value of the long-run coefficient of income is lower than that of the short-run coefficient, implying that the impact of global economic growth, on global emissions, is relatively profound in the short run. Thus, we conclude that the EKC hypothesis exists across the globe. These results are also backed by the study of Narayan and Narayan (2010) and Danish et al. (2020). Next, the value of GEN is 10.65. Since GEN is also statistically significant, we can explain that a 1% surge in global energy consumption escalates the global carbon emissions by 10.65%, ceteris paribus. This outcome of the present study is similar to the conclusion of Anser et al. (2021a).

Finally, the diagnostics of the bootstrap ARDL model are presented in panel III. The Adj. R-square is 0.78, indicating that the dependent variable is explained by 78% through independent variables. Next, the value of the Ramsey RESET test is 0.51, suggesting that the model is well specified. Moreover, the LM test is employed to discern the correlation among errors (residuals). The calculated value from the LM test is 0.29, suggesting that there does not exist a correlation among errors. Further, CUSUM and CUSUM-square test depicts the stability of the model. The Jarque–Bera test is employed to probe the distribution of errors. The p-value from the test is 0.17, implying that errors (residuals) are normally distributed. The value from the ARCH test is 0.29, reporting that there does not exist the issue of heteroscedasticity. Next, the ECT is statistically significant with a value of − 0.19. This expounds that any shock in the long-run equilibrium will be covered by 19% each year.

Sensitivity analysis

This section presents two sensitivity checks to provide robust outcomes. First, we employ the conventional EKC hypothesis (i.e., inverted U-shaped income-environment relationship) to probe whether the choice of model alters the findings. Second, we employ FMOLS, DOLS, and CCR estimators to explore whether the results remain consistent across different methodologies. Table 6 reports findings from the bootstrap ARDL approach using the conventional EKC model.

As can be seen from the above-mentioned table, the coefficient of GGDP and GGDP2 has a positive and negative sign, respectively. Also, these aforementioned coefficients are statistically significant, confirming that EKC does exist in both the short- and long run. Further, the coefficient of GPR is negative and statistically significant in the short run, whereas it is positive and statistically significant in the long run. This implies that GPR plunges the emissions in the short run, whilst it increases the emissions in the long run. The coefficient on GEN is positive and statistically significant in both the short and long run, inferring that energy consumption leads to higher emissions. Moreover, all the diagnostics presented in panel III show that the model is stable and the residuals are also well-behaved. It is worth reporting that findings from both models, i.e., conventional EKC and EKC developed by Narayan and Narayan (2010) are consistent, confirming that choice of theoretical/empirical model does not affect the outcomes.

Second, we report the findings from FMOLS, DOLS, and CCR estimators in Table 7. The coefficient of GGDP is statistically significant and contains a positive sign from FMOLS, DOLS, and canonical cointegrating regression (CCR) estimators, reporting that economic growth leads to higher emissions globally. Next, the coefficient of GEN is also statistically significant and possesses a positive sign, confirming that energy consumption escalates emissions. Finally, the coefficient on GPR is statistically significant and positive, inferring that geopolitical risk contributes to high levels of emissions. It is worth reporting that the coefficient on GPR is positive and statistically significant across all estimators (i.e., FMOLS, DOLS, and CCR). Also, the findings

Table 6 Findings from bootstrap ARDL (2, 2, 1, 3) approach

Indicator	Value	Probability value
Short-run estimates (panel I)		
ΔGPR_t	− 1.10	0.00***
$\Delta GGDP_t$	0.11	0.00***
$\Delta GGDP2_t$	− 0.02	0.00***
ΔGEN_t	1.32	0.00***
Long-run estimates (panel II)		
GPR_{t-1}	10.12	0.03**
$GGDP_{t-1}$	1.26	0.02***
$GGDP2_{t-1}$	0.32	0.00***
GEN_{t-1}	4.13	0.02***
CO_{2t-1}	− 0.13	0.10
Diagnostics (panel III)		
R^2 (adjusted)	0.71	
Ramsey RESET test	(0.33)	
LM test	(0.21)	
CUSUM test	Stable	
$CUSUM^2$ test	Stable	
Jarque–Bera test	(0.21)	
ARCH test	(0.19)	
ECT	− 0.35***	

GGDP2 denotes the squared term of global GDP. Also single, double, and triple asterisks denote the level of significance at 1%, 5%, and 10%, respectively

Table 7 Findings from FMOLS, DOLS, and CCR approach

Indicator	FMOLS	DOLS	CCR
GGDP	0.12***	0.22***	0.36***
GPR	0.05***	0.07***	0.02***
GEN	1.23***	0.91***	2.72***

Single, double, and triple asterisks denote the level of significance at 1%, 5%, and 10%, respectively from these aforementioned methodologies are inconsistent with the outcomes from bootstrap ARDL.

Conclusion

Nowadays, geopolitical risk (GPR) has been increasing across the globe. Further, GPR has both economic and environmental impacts; however, its environmental impacts yet remain unclear due to contrasting outcomes. To fill this gap, the present study investigates the impact of global GPR on global carbon emissions using a novel methodology of bootstrap ARDL approach. The findings from ADF and ZA unit root test reveal that the selected variables of this study are integrated at I (1). Moreover, the results from the bootstrap ARDL bounds test confirm the long-run relationship (co-integration) among the considered variables. Next, we report that energy consumption leads to a higher level of emissions in both the short and long run. Additionally, we report the validity of the EKC hypothesis put forward by Narayan and Narayan (2010). The results also document that GPR impedes global emissions in the short run, whereas it escalates the emissions in the long run. Finally, we use two procedures for the sensitivity analysis: (1) conventional EKC model to check whether the choice of model alters the key findings; and (2) FMOLS, DOLS, and CCR estimators to probe whether the choice of methodology affects the main findings. We confirm that the conventional EKC hypothesis does exist globally, and the GPR has a negative and positive impact on emissions in the short and long run, respectively. Moreover, the findings from FMOLS, DOLS, and CCR estimators reveal that GPR upsurges emissions in the long run, which is consistent with the main findings from the bootstrap ARDL approach.

Moreover, the current study proposes several implications. First, policymakers should try to devise policies to achieve higher economic growth, especially in the long run, to control environmental degradation. To improve income/economic growth, countries should invest in green technologies, R&D, and renewable energy projects, which will enhance the rate of economic growth without affecting environmental quality. Second, the share of renewables in the energy mix should be improved to impede global carbon emissions. In addition to this, there should be subsidies from the governments while investing in renewable energy projects. Next, governments should introduce tariff rationalization on imports of renewable energy-based products. Additionally, to discourage non-renewable energy, governments should impose high taxes and/or tariffs on non-renewables. Governments and international organizations should launch public awareness programs to make people understand the harmful environmental impacts of non-renewable energy. Further, in the short run, policymakers need to adopt measures (e.g., R&D, innovations, and human development) that help to ameliorate environmental quality without affecting GPR. Additionally, in the short run, governments should pay attention to the detrimental economic impacts of GPR. Therefore, governments should introduce expansionary demand- and supply-side policies to offset the harmful economic impact of GPR. However, in the long run, there should be agreements, treaties, and negotiations among countries to plunge GPR since it has detrimental environmental impacts. In addition to this, international organizations should play their role (e.g., as a moderator) to resolve the conflicts between nations to limit GPR. Further, the world's leaders (e.g., the USA and China) should resolve their geopolitical tensions (e.g., USA-China trade war) since these geopolitical tensions not only affect them but also have spillover effects on the rest of the world. In the long run, strict environmental protection measures should be taken in times of high geopolitical tensions to keep the environment clean. For instance, high carbon prices and active environmental stringency policies could be adopted by the governments during the high geopolitical tensions.

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Data availability Available upon request.

Declarations

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