



How economic policy uncertainty and geopolitical risk affect environmental pollution: does renewable energy consumption matter?

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Received: 21 March 2023 / Accepted: 23 August 2023 / Published online: 2 September 2023
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Abstract

Climate change traps heat, affecting various species in previously dry areas. Climate change brought on by emissions of greenhouse gases exacerbates problems such as severe storms, earthquakes, epidemics, and food distribution. The group of developed and developing countries, the world's biggest carbon emitters and most significant economies, is expertly planning to lessen its environmental challenges and contribute to achieving Sustainable Development Goals 7 and 13 set by the United Nations. This study uses the novel econometric methodologies of the dynamic ordinary least square (DOLS) estimator, the augmented mean group (AMG) estimator, and the fully modified ordinary least square (FMOLS) estimate to examine the influence of economic policy uncertainty, renewable energy consumption, geopolitical risk, non-renewable energy consumption, and economic growth on ecological footprint from 2000 to 2021. The results reveal that the variables are co-integrated; REC reduces carbon emissions, EPU, geopolitical risk, and economic growth contribute to increasing carbon emissions, while urbanization improves carbon emission. Finally, the results suggest that the developed and developing economies can progress toward SDGs 7 and 13 by using renewable energy, lowering the geopolitical risk, effectively handling policy uncertainty, and reducing urbanization.

Keywords Economic policy uncertainty · Ecological footprint · Non-renewable energy consumption · Renewable energy consumption · Geopolitical risk

Responsible Editor: Arshian Sharif

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Introduction

Global warming is one of the most challenging issue in the world causing climate change. From the origin of the industrial period, the Earth's average temperature has been steadily mounting. Emissions of greenhouse gases (GHGs) have been rising steadily and are already 50% higher than their pre-industrial levels, a well-known cause of this phenomenon (Sharif et al. 2019). The member nations of the United Nations have decided to keep the growth in global average temperature to 1.5 °C, a target that will require significant worldwide commitments to attain (Godil et al. 2021). China has started working to decrease its CO₂ emissions per unit of GDP by 60–65% at the end of 2030. The work on this goal was started in 2005, as it was agreed upon in the Paris climate deal, and there it was decided that China would enhance the use of renewable energy to reduce CO₂ emission (Chien et al. 2022). The SDGs state that nations must be protected from geopolitical concerns in order for environmental quality assurance agencies to

function (Li et al. 2023b). Hashmi et al. (2022) make a similar case, arguing that international peace and understanding boost economic sustainability, encourage collaboration, and cut down on the use of carbon-intensive fuels.

From the beginning of twenty-first century, global events with significant consequences, such as the 2008 financial catastrophe and the COVID-19 outbreak of 2020, have developed, causing drastic variations in the economic position and the constant updating of economic policy. Due to these extreme events, issues like global climate risk, economic policy uncertainty (EPU), geopolitical and economic unrest, anti-globalization practices, a revival of trade isolationism, and other such phenomena have happened (Suki et al. 2020). Scholarly interest in the EPU has been rising recently. The development and functioning of the carbon market strongly rely on government financial programs, making the carbon market extremely sensitive to changes in EPU (Khan et al. 2019). Many scholars have looked into the connection between the EPU and carbon emission while the link between EPU and ecological footprint (EF) has been studied by some studies and mixed results have been found from previous studies. According to Wan et al. (2022), EPU positively impacts ecological footprint, those of Jian and Afshan (2022), which showed the opposite that EPU reduces ecological footprint, present conflicting viewpoints. This study examines the relationship between EPU, geopolitical risk, GDP, natural resource consumption, and EF to reduce the harmful effects of these factors on environmental sustainability.

In addition to economic policy uncertainty, Xiangyu et al. (2021) emphasized the need for managerial authorities to tackle the rising challenges associated with the geopolitical risk (GPR), such as the fallout from 9/11, the Bombay outbursts, and the US-China trade war, all of which continue to haunt the present ecological quality by discouraging investors, financial institutions, and business owners from launching a green business practices. This, however, corroborates the macro-level effects of GPR on developed and developing nations, as seen by the region's economic decline and rising externalities (Irfan et al. 2022). However, many studies emphasize the reasons behind GPR that affect the tourism business (Li et al. 2022a), increase classical means of energy usage (Saqib et al. 2023), and increase financial liquidity and oil prices (Hashmi et al. 2021); these results lead to CO₂ emissions. Furthermore, producers are prompted to set up carbon-based industrialized markets due to the GPR, which reduces economic output by deterring innovativeness. Conflicts between nations often result in the widespread destruction of natural habitats and a rise in the deficit ratio of EF (Anser et al. 2021a). They also looked into the obviousness of the suffering associated with transforming renewable energies due to geopolitical danger.

Therefore, in-depth research on the origins and effects of ecological footprint and the impact of GPR on natural resources is essential.

While it is true that having access to plenty of natural resources can help lessen environmental damage (Syed et al. 2022), it is also true, as stated by Syed and Bouri (2022a), that industrialization cannot be carried out without using them, and that the process of extracting them furthers agricultural output, alters the climate, and speeds up deforestation. The garbage produced by these commercial operations contributes to environmental degradation. However, the conversion from renewable to non-renewable resources in production significantly affects carbon dioxide emissions (Chang et al. 2019). Despite resource wealth and rapid economic development, resource-intensive countries like China face environmental issues (Syed et al. 2021). To attain the status of efficient use of energy and maintaining a stable global climate, several countries offer subsidies for fossil fuels, increasing their carbon footprint. The energy required to flush waste compounds into the air, water, and ground is another way that steady extraction aids in reducing ecological decomposition. The negative consequences of ecological pollution can be lessened by the careful and efficient use of natural resources and through green mining and mineral extraction practices (Anser et al. 2021b).

In this regard, the Paris Climate Change Accord is central to discussions about climate change and how to address the problem best. Nonetheless, regarding processing worries about climate change, the UK's relevance is relatively low compared to Europe and other affluent nations. Although conforming to EU regulations, the UK's air quality programs could have been more effective. That becomes apparent during a discussion on the proposed bill, which purpose is to attain zero carbon by 2050 (Caglar et al. 2021). In France, a pre-ecological policy was established to remove the issue of EPU; the ecological safety measures were also met with opposition from the Yellow Vest protest movement. This highlights the need for responsible policymaking by government institutions to safeguard the environment (Pata and Caglar 2021). A country's economic policies significantly influence its climate, and ecological quality is linked to these policies. An index now quantifies the degree of unpredictability surrounding future economic policies.

The realization of the SDGs is currently the primary focus of many countries because of their attention to social, economic, and environmental concerns. Adverse effects on economic actors can be attributed to global ecological problems such as global warming and air pollution. In recent years, scientists have focused a great deal of attention on discovering the causes of carbon dioxide (CO₂) emissions and developing effective strategies for reducing them. This study adds to the current dialogue about environmental policy. This research aims to answer the following scientific

questions: (1) What is the impact of EPU and geopolitical risk on environmental pollution in specific groups of developed and developing countries? (2) In the presence of EPU and GPR, what is the role of RE consumption on environmental pollution? (3) How do economic growth, fossil fuel consumption, and urbanization affect environmental pollution? In addition, we use the fully modified ordinary least square (FMOLS) estimator, the dynamic OLS (DOLS) estimator, and the augmented mean group (AMG) estimating approaches to identify the origins of environmental pollution, which other estimation techniques may have ignored. Finally, the study's findings would strengthen the overall goal of creating a more resilient and sustainable economy by aiding in formulating SDG-based strategies that would assure net-zero GHG emissions by 2050.

What follows is the outline for the rest of the paper. The "Literature review" section summarizes the research done on carbon prices and provides theoretical context. The "Data and methodology" section consisted of an overview of the methodology and dataset. In the "Empirical results" section, we apply the multiple models to the empirical findings. A discussion of the findings and their pertinent consequences is given in the "Conclusions and policy implications" section.

Literature review

Impact of economic policy uncertainty (EPU) on environmental pollution

Economic policy uncertainty (EPU) may affect how quickly a country or region implements solutions to reduce carbon dioxide emissions. Hence, research has been done from both time series and panel assessments. Husnain et al. (2022) research used conventional ARDL on the UK economy to determine EPU's role in environmental degradation. He did this by adjusting for factors like economic growth and energy consumption; his findings revealed that the short-term effects of EPU on the atmosphere were negligible, while the long-term effects were positive. Similar but more pronounced effects of energy use on environmental degradation were also seen. Yet, wealth has been shown to have a salutary effect on the environment. However, Li et al. (2023a) used the novel augmented ARDL technique to find the influence of EPU on CO₂ emissions in France and found that EPU worsened the environment over the long run.

By adjusting for factors like energy consumption and GDP growth, Syed and Bouri (2022b) were able to determine whether or not EPU influences CO₂ emissions in China, and they found that it did not. The study found that energy usage and economic expansion have long-term adverse environmental effects. However, by running the renowned dynamic ARDL simulations, we learned how

EPU, income, energy intensity, population, and economic structure determine environmental deterioration in China (Anser et al. 2021c). The result proved that environmental damage can occur when economic policy is unstable. Similar to how affluence, population, and energy intensity devastate the ecosystem. Without following the expectations, the study found that economic structure improves ecological sustainability.

Bhowmik et al. (2022a) used balanced panel data for 30 provinces between 2003 and 2017 to observe the influence of EPU on CO₂ emissions and show that this uncertainty develops environmental quality. Nonetheless, the study found that eco-laws and energy use lower environmental standards. Bhowmik et al. (2022b) researched the consequence of EPU on CO₂ emissions in Chinese cities and found that any increase in policy uncertainty increased CO₂ emissions.

To find the impact of EPU on carbon emissions in 22 OECD nations, Liu et al. (2022a) adjusted for energy use and GDP growth. PMG-ARDL was used to prove that long-term increases in CO₂ emissions are caused by economic policy uncertainty. However, the research showed that short-term energy and economic expansion reduce environmental sustainability. Hashmi et al. (2021) observed the part of EPU in influencing environmental quality in BRICS countries, showing that it boosts environmental quality through second generation unit root and cointegration techniques. Nevertheless, the energy structure and associated technologies had a devastating effect on ecological conditions.

In addition, Li et al. (2022b) studied the influence of EPU on CO₂ emissions (EM) in the five most polluted economies while accounting for variables such as RE, income, and ecological innovations, and they found that EPU worsened environmental quality. However, all of the manipulated variables improved the environment.

Impact of geopolitical risk (GPR) on environmental pollution

Environmental pollution is linked to geopolitical risk, as stated by Tang et al. (2022). At its core, the phenomenology of geopolitics outlined by Ameer et al. (2023) links global affairs and geography with the structural pillars of eternal rivalry, territory, and colonial military superpowers. These elements, it says, affect ecosystems and contribute to environmental contamination. As a result of this trend, only a few eco-activists recognize the role of geopolitical risk in increasing CO₂ emissions. From 1993 to 2018, Hailiang et al. (2023) used the ARDL method to observe Russia's energy transition strategies while considering geopolitical risk. The estimates showed that the transition to a more sustainable energy system and the emergence of new climatic patterns due to political upheavals are positively correlated. Research by Hai Ming et al. (2022), highlights the knock-on

effect that geopolitical crises in China have on renewable energy.

It was also asserted that the unrest on the India-China boundary had severe consequences and jeopardized economic and societal stability (Nasir et al. 2022). The Granger rolling-window estimation and GPR index are used in this study, and the results suggest that the Chinese government should consider using GPR to curb CO₂EM by developing other environmentally friendly businesses and maintaining existing ones. Second, the energy sector is China's principal producer of GPR. It has been pointed out that China's energy supply and dependence on imported energy sources could be a problem (Mngumi et al. 2022). If shipping lanes were closed, China, the world's greatest energy consumer, would face supply challenges. To that end, Du et al. (2022) suggested that China deepen ties to Central Asia to enhance its imports and thereby slake the demand for energy security.

On the other hand, doing so would lead to complicated questions relating to energy rivalry and enhanced competition among significant nations. Furthermore, Wei et al. (2022a) studied the GPR in BRICS nations using the NARDL technique. They show that CO₂EM are a positive GPR coefficient and ecological externalities rise quickly.

To determine a causal link between GPR and CO₂EM, Li et al. (2023b) have substituted political disturbance, terrorist activities, combat, and other indicators for GPR. CO₂EM are significantly impacted negatively by the geopolitical ramifications and government effectiveness of BRICS states like China. The EKC theory is tested by analyzing the data for heterogeneity and CD from 1990 to 2018. The research results for both AGM and CCEMG expounded on the moderating influence of GPR on CO₂EM. Ma et al. (2022) looked at eight different nations, involving Pakistan and found that the medium of terrorism increased CO₂EM. Terrorism is linked to increased CO₂EM, higher energy use, and a larger ecological footprint (EF), as studied by Ahmed et al. (2022), looking at the two countries, China and Pakistan, and their responses to these issues.

Research gap

The above given literature shows that EPU, GPR, and economic impact on environmental pollution have been measured by many studies. However, renewable energy and previous studies have not studied non-renewable energy consumption. Furthermore, previous studies use ARDL, quantile-on-quantile regression, VECM, and many other models. However, this study uses multiple advanced econometric models, including FMOLS, DOLS, and AMG, simultaneously to get more accurate results which the previous studies have yet to consider. In addition, we have concluded from previous studies that a set of developed or developing countries has been chosen for analysis.

However, we have taken developed and developing countries simultaneously in this research and compared the results. As a result, this study seeks ways to reduce the development of carbon-intensive resources while resolving the underlying conflicts.

Theoretical framework

Here, we have theories about how EPU and GPR affect CO₂EM. Li et al. (2023c) state that there are two effects/channels between EPU and CO₂ emissions: indirect policy demand effect and direct effect on policymaking. An increase in EPU shifts policymakers' attention away from protecting the environment and toward preserving economic growth, as seen by the direct policy alteration effect. In consequence, economic CO₂ emissions increase. Concurrently, evidence from the indirect policy demand channel demonstrated that the EPU influences consumers' and producers' decisions and economic behavior, leading to higher overall energy consumption. Because of this, CO₂ emissions have skyrocketed in the country.

EPU changes carbon emissions via investment and energy consumption pattern, as the same concept has been given by Firdaus et al. (2022). It has been noticed that EPU reduces energy consumption and products which are carbon intensive. That is why the consumption effect suggests EPU, so EPU reduces the CO₂ emission into the environment. On the other hand, EPU is shown to reduce spending on R&D, technical progress, and new inventions in studies surveying the association between expenditure and effect. Carbon monoxide emissions will rise accordingly as EPU increases.

The same three channels connecting economic policy uncertainty and CO₂ emissions were developed by Firdaus et al. (2022). Innovations, the percentage of energy generated from fossil fuels, and energy intensity comprise these three pathways. Policy-related uncertainties reduce innovation, increasing CO₂ emissions, as the innovation channel shows (Caglar et al. 2022). Finally, the fossil fuels channel explains how EPU increases the use of fossil fuels in the whole energy mix, which in turn causes a rise in EF. Furthermore, the energy intensity channel describes how EPU raises energy intensity, increasing ecological footprint.

Similarly, Weimin et al. (2022) propose GPR's increasing effect and moderating effects, which connect GPR to environmental degradation. The cumulative impact of GPR is inhibiting research and development (R&D), technological progress (T&D), and new forms of innovation. It will lead to a rise in CO₂ released into the atmosphere, and EF will also rise. On the other hand, the mitigating effect claims that GPR will result in lower CO₂ emissions since it will cause a reduction in economic activity and energy use.

Table 1 Variables’ measurement and description

Variables	Symbols	Description	Source
Ecological footprint	EF	Gha per person	GFN
Economic policy uncertainty	EPU	An index based on the number of times newspapers mentioned the expiration of tax laws, economic projection uncertainties, and other associated policy issues	www.policyuncertainty.com
GDP per capita	GDP	GDP per capita (constant 2010\$ US)	WDI
Urbanization	URB	% of population live in urban area	WDI
Geopolitical risk index	GPR	How many news stories included geopolitical terminology (e.g., geopolitics and uncertainty)	Policyuncertainty.com
Renewable Energy Consumption	REC	% of total final energy consumption	WDI
Non-renewable energy consumption	NREC	Use of renewable energy out of total energy use	WDI

“GFN” indicates global footprint network

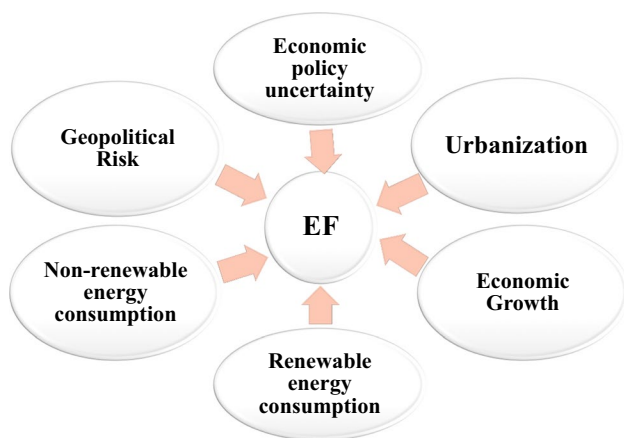


Fig. 1 Relationship among variables

Data and methodology

This study examines what causes economic policy uncertainties (EPU) in industrialized and emerging nations, including the UK, Pakistan, the USA, China, and India. In particular, this study observes the interplay between EPU and renewable energy consumption (REC), looking at the years 2000–2021 for the UK, the USA, China, and India, and

the years 2010–2021 for Pakistan, where data is more readily available. EPU indices (<https://www.policyuncertainty.com/>) provided the annual EPU dataset, while the World Bank data indicators (WDI) provided the rest of the study variables listed in Table 1 and the relationship has been shown in Fig. 1. To facilitate a more thorough and comprehensive analysis, we have changed our annual time series into quarterly data, as suggested by William and Fengrong (2022). The economic policy uncertainty for the USA and the UK is falling, while China, Pakistan, and India are increasing.

We logarithmically transform all factors to control for heteroscedasticity (Bai 2021). Table 2 also emphasizes the data’s descriptive numbers.

Table 2 shows that REC has the highest standard deviation. This finding suggests high volatility levels in series tracking renewable energy. Results show that each series has either a favorable or unfavorable skew. The Jarque-Bera test demonstrates that all factors, except GPR and EPU, do not follow a normal distribution.

Model and methodology

We use the IPAT (impact = population, affluence, and technology approach), which looks at the environmental implications of human activities, to study the

Table 2 Descriptive statistics

Statistics	Mean	Median	Maximum	Minimum	Std. dev.	Skewness	Kurtosis	Jarque-Bera
EF	1.07	1.07	1.77	0.60	0.33	0.462	2.3205	0.0315**
NREC	7.32	7.31	8.55	6.42	0.64	0.5985	2.4045	0.0105**
EPU	7.10	7.09	8.38	5.78	0.48	−0.0525	3.171	1.0185
GDP	8.81	9.04	9.39	7.11	0.54	−1.5435	4.851	0.000
GPR	7.04	7.04	7.52	6.53	0.18	−0.063	3.171	0.9975
URB	18.95	18.78	21.03	17.41	1.11	0.798	2.8035	0.000
REC	2.73	2.87	3.89	1.17	0.9	−0.4935	2.0265	0.000

** denotes level of significance at 5%

relationship between geopolitical risk (GPR), economic policy uncertainty (EPU), and ecological footprint (EF) (Rehman et al. 2021):

$$EF_{it} = \beta_0 + \beta_1 GDP_{it} + \beta_2 NREC_{it} + \beta_3 REC_{it} + \beta_4 URB_{it} + \beta_5 EPU_{it} + \beta_6 GPR_{it} + \epsilon_{it} \tag{1}$$

The econometric model we create for this investigation is depicted in Eq. (1), where *i* denotes the cross-section and *t* denotes time. *ε_{it}* represents the model’s error term. Ecological footprint is abbreviated as EF. Next, we have GDP, NREC, REC, URB, EPU, and GPR, which stand for gross domestic product per capita, non-renewable energy consumption, renewable energy consumption, urbanization, economic policy uncertainty, and geopolitical risk. The IPAT model uses the rate of increase in the gross domestic product (GDP) as a proxy for prosperity, the population as a proxy for the ecological influence of growth, and population and NREC as a proxy for fossil fuel energy consumption. Environmental deterioration typically increases alongside economic growth, population growth, and the use of fossil fuels, according to Pata and Caglar (2021). Renewable energy, on the other hand, has been shown to worsen environmental conditions (Guloglu et al. 2023).

If the variables are cointegrated, the OLS method fails to estimate long-term coefficients accurately. However, methods like DOLS and FMOLS (fully modified ordinary least squares) are more suited to the circumstances. Sequence correlation and endogeneity could be corrected using both DOLS and FMOLS. It is hard to say which approach is best. As a non-parametric method, the FMOLS accounts for variation across multiple time points. It corrects autocorrelation and heteroscedasticity by cutting off the link between the explanatory variable and the random interference component. The covariance structure estimates and the asymptotic normality distribution of the FMOLS estimator are derived from this unified method. As a result, covariance parameters can be tested with the traditional Wald statistic without worrying about the effect of duplicated parameters on the limit distribution of the test statistic. According to Kao and Chiang (2001), the parametric DOLS method is superior to the FMOLS approach.

On the other hand, Pedroni (2001) demonstrated that, compared to FMOLS, DOLS produced less size distortion throughout the estimating process. In contrast, DOLS is a parametric method. This method involves including the lag term of the explanatory variable in the cointegration equation to weaken the relationship between the explained variables and the error terms. The following are the parameters for the FMOLS and DOLS panels:

$$\hat{\beta}_{FMOLS} = \left[N^{-1} \sum_{i=1}^N \left(\sum_{t=1}^T (p_{it} - \bar{p}_i)^2 \right) \right]^{-1} \times \left[\sum_{t=1}^T (p_{it} - \bar{p}_i) \right] \hat{S}_{i,t} - T \Delta_{\epsilon_{it}} \tag{2}$$

$$\hat{\beta}_{DOLS} = \left[N^{-1} \sum_{i=1}^N \left(\sum_{t=1}^T W_{i,t} z'_{i,t} \right)^{-1} \left(\sum_{t=1}^T W_{i,t} \tilde{S}_{i,t} \right) \right], \tag{3}$$

here the FMOLS and DOLS estimators are represented by Eqs. (2) and (3). Several studies have shown that correlating panel sections using FMOLS and DOLS can lead to erroneous conclusions. This study employs the augmented mean group estimator (AMG), which provides adequate findings despite the abovementioned issue. When applied to non-stationary data, the AMG estimator outperforms FMOLS and DOLS. Testing for unit root and co-integration is not essential before using the AMG estimator. The two-stage process that constitutes AMG is outlined below.

First, we use a dummy variable for time interval T–1 and the first difference of each series to arrive at an estimate of Eq. (1):

$$\Delta EF_{it} = \beta_0 + \beta_1 \Delta GDP_{it} + \beta_2 \Delta NREC_{it} + \beta_3 \Delta REC_{it} + \beta_4 \Delta URB_{it} + \beta_5 \Delta EPU_{it} + \beta_6 \Delta GPR_{it} + \sum T_t = 2\tau_t(\Delta Dt) + \epsilon_{it} \tag{4}$$

Dummies at the first difference for periods T–1 are denoted by ΔDt in Eq. (4). Period dummies, or Pt, are parameters that represent time intervals. The second stage entails reshaping parameters (pt) as a new variable (τt) that represents the shared dynamic process. Below, details of the model are provided as follows:

$$\Delta EF_{it} = \beta_0 + \beta_1 \Delta GDP_{it} + \beta_2 \Delta NREC_{it} + \beta_3 \Delta REC_{it} + \beta_4 \Delta URB_{it} + \beta_5 \Delta EPU_{it} + \beta_6 \Delta GPR_{it} + di(\tau_t) + \epsilon_{it} \tag{5}$$

$$\Delta EF_{it} - \tau_t = \beta_0 + \beta_1 \Delta GDP_{it} + \beta_2 \Delta EN_{it} + \beta_3 \Delta REN_{it} + \beta_4 \Delta POP_{it} + \beta_5 \Delta EPU_{it} + \beta_6 \Delta GPR_{it} + \epsilon_{it} \tag{6}$$

The average values of parameters in the group-specific model are determined first after modifying the model using τt. The parameter of EPU, for instance, can be found by solving for β5, AMG=1N∑Ni=1β5, i. The problems of heterogeneity and CD are considered by the AMG estimator. In addition, the AMG estimator yields reliable results (Shen et al. 2021).

We also use the heterogeneous panel causality test to investigate potential causation. This test, an improved form of the panel granger causality technique, yields reliable findings even in the face of CD (Gu et al. 2021). We provide the D-H test protocol below.

$$W_{N,T}^{HNC} = \frac{1}{N} \sum_{i=1}^N W_{i,t} \tag{7}$$

Table 3 Results of CSD

Variables/tests	LM	P-value	CD _{LM}	P-value	LM _{adj}	P-value	CD	P-value
EF	148.78	0.00	31.03	0.00	30.91	0.00	12.11	0.00
REC	180.67	0.00	38.16	0.00	38.04	0.00	13.42	0.00
NREC	117.53	0.00	24.04	0.00	23.93	0.00	2.63	0.00
GPR	23.62	0.00	3.05	0.00	2.93	0.00	0.45	0.65
EPU	36.77	0.00	5.99	0.00	5.87	0.00	5.41	0.00
GDP	173.43	0.00	36.54	0.00	36.42	0.00	13.13	0.00
URB	92	0.00	18.34	0.00	18.22	0.00	5.4	0.00

Table 4 Cross-sectional dependence test for the whole model

Model	EF = f (GDP, NREC, REC, EPU, GPR, URB)
Breusch-Pagan LM	(26.11) 0.000
Pesaran Scaled LM	(3.60) 0.000
Pesaran CD	(2.84) 0.000

$$Z_{N,T}^{HNC} = \sqrt{\frac{N}{2K}} \left(W_{N,T}^{HNC} - K \right), N(0, 1) \tag{8}$$

The Wald statistic is denoted by $W_{i,t}$ by averaging each Wald static for cross-sections, however, we may determine WHNCN, T.

Empirical results

The empirical process utilized in the present study is well-arranged as follows: since shocks in one nation may have unintended consequences in another if they are linked with independent variables, we first test for CD in our data to see if there is any evidence of such spillover. The Pesaran LM test, the Breusch-Pagan LM test, and the Pesaran CD test are three of the most popular CD tests in the literature. In this work, we employ these three CD tests; the findings are shown in Table 3. In Table 4, CSD as a whole for the model has been presented.

Table 4 demonstrates that the probability value is significant at the 1% significance level. Hence, the null hypothesis can be rejected. As a result, we find evidence of cross-sectional correlation. Next, we use a test for slope homogeneity (Pesaran and Yamagata 2008). The Δ^{\wedge} and

Δ^{\wedge} adj. values are the basis of this analysis. Table 5 displays the results, which reveal that all slopes differ from one another, except the slope of the GPR.

Finally, we check to see if the data follow a stable process, which would prevent erroneous regression. We employ the least squares (LS), IPS, CIPS, and PP-Fisher unit root tests for this. It is important to note that the problems of heterogeneity and CD are addressed by the CIPS unit root test. In Table 6, the findings from the unit root tests are given.

Table 5 consisted of results from unit root tests. The outcomes of each test for a unit root indicate that the absence of a unit root cannot be rejected as a null hypothesis. In contrast, at 0 (1) the null hypothesis can be rejected. At level 1 (1), all variables are linked.

Fourth, since the variables are assumed to be stationary, after the first difference, we test whether or not their linear combination is also stationary. This co-integration holds if and only if the linear blend of these variables is stationary. Here, we use the Kao cointegration test (Kao and Chiang 2001) to investigate the possibility of cointegration between the variables. However, this test may produce false positives when there is CSD and heterogeneity. We also used the cointegration test proposed by Westerlund and Edgerton (2007), which is robust in the presence of heterogeneity and CD, to overcome this restriction. Table 7 shows the outcomes of the Kao and Westerlund tests.

The results of the co-integration tests are shown in Table 7. The probability values are significant at the 1% and 5% level; therefore, we can rule out the possibility of cointegration. Therefore, we infer that the variables are cointegrated or have long-run linkages between them. The findings from multiple tests have been shown in Table 8.

Table 5 Results from homogeneity test

Statistics	EF	GDP	NREC	REC	URB	EPU	GPR
Δ^{\wedge}	23.45*** (0.00)	12.34*** (0.00)	9.04 *** (0.00)	3.04 *** (0.00)	9.09 *** (0.00)	2.73 *** (0.00)	0.63 (0.05)
Δ^{\wedge}_{adj}	12.05 *** (0.00)	15.37 *** (0.00)	8.64 *** (0.00)	3.25 *** (0.00)	9.73 *** (0.00)	2.93 *** (0.00)	0.6 (0.05)

*** indicates level of significance at 1%.

Table 6 Unit root tests

Variable		EF	NREC	EPU	GDP	GPR	URB	REC
Level	LLC	-0.36	-0.95	-0.92	-1.00	-0.21	-1.00	-0.25
	IPS	-0.17	-0.9	-0.84	-1.00	-0.14	(0.00) **	-0.41
	PP-Fisher	(0.00) ***	(0.00) ***	-0.81	(0.02) **	(0.08) *	(0.00) **	(0.00) ***
	CIPS	-0.19	-0.90	-0.95	-0.96	-0.19	-1.32	-0.17
First Difference	LLC	(0.09) *	(0.00) ***	(0.00) ***	(0.00) ***	(0.00) ***	(0.00) ***	(0.00) ***
	IPS	(0.00) ***	(0.00) ***	(0.00) ***	(0.00) ***	(0.00) ***	(0.00) ***	(0.00) ***
	PP-Fisher	(0.00) ***	(0.00) ***	(0.00) ***	(0.00) ***	(0.00) ***	(0.00) ***	(0.00) ***
	CIPS	-2.70***	-3.57***	-3.21***	-2.98***	-2.66***	-2.83***	-2.65***

* $P < 0.05$, ** $P < 0.10$, *** $P < 0.01$

Table 7 Co-integration results.

Test	Statistic	Probability
Kao test	-4.1895	0.000
Westerlund test		
P_t	-3.717***	0.000
P_a	-4.998***	0.000
G_t	-4.4415***	0.000
G_a	-6.279***	0.000

The null hypothesis of both tests assumes no cointegration. *** shows 1% level of significance

Table 8 Results from FMOLS, DOLS, and AMG estimators

Variable	FMOLS	DOLS	AMG
GDP	0.316 (0.004) *	0.087 (0.002) *	0.076 (0.004) *
NREC	0.154 (0.001) *	0.765 (0.004) *	0.387 (0.009) **
REC	-0.256 (0.007) **	-0.032 (0.001) *	-0.145 (0.017) **
URB	0.045 (0.021) **	0.654 (0.007) **	-0.345 (0.012) **
EPU	0.064 (0.015) **	0.098 (0.016) **	0.183 (0.009) **
GPR	-0.139 (0.005) *	-0.865 (0.022) **	-0.216 (0.005) *

* = 1%, ** = 5%, *** = 10%

FMOLS results show that all coefficients significantly differ from zero at the 1% level. In particular, the GDP coefficient is 0.316%, which means that a rise of 1% in GDP results in a 0.316% increase in the EF, indicating that an increase in the income level of the emerging countries panel increases its ecological footprint. These outcomes are reliable to those found in the literature (Adebayo 2022). As a bonus, the coefficient of NREC is 0.154%, which means that a 1% rise in NREC results in an EF surge of 0.154%. Repeated research has shown the same results (Li et al. 2023a). With a REC for renewables of -0.256, switching to renewable power sources will affect positively the environment by lowering the usage of fossil fuel. This data agrees with earlier research (Husnain et al. 2022).

Similarly, URB has a 0.045% coefficient, indicating that population has a negligible impact on EF. However, since 0.064% is the coefficient of EPU, a 1% rise in EPU encourages a 0.064% rise in EF. The coefficient of GPR is -0.139%, which indicates that a 1% rise in GPR results in a 0.139% decrease in EF.

In a similar vein, all DOLS coefficients are found to be statistically significant at the 1% level. A closer look reveals that GDP, NREC, and URB increases contribute to rising EF. However, REC has the opposite effect and reduces EF. Even more convincingly, the coefficient of EPU shows that EPU improves EF. However, since the coefficient of GPR is negative, we can infer that GPR reduces EF. Our study results are consistent with previous studies (Caglar 2023).

When using the AMG estimator, we find that all coefficients are highly significant, except URB, which is not. In addition, the AMG estimator shows that GDP and NREC increase boost EF. In addition, like the earlier stated estimators, REC causes the EF to drop. Next, the coefficient of EPU is 0.10, which demonstrates that the environmental risks grow with the degree of ambiguity surrounding the economic policy of the analyzed panel countries. The causes of this outcome are difficult to pinpoint. For instance, EPU reduces investment in research and development and technology, speeding up environmental deterioration. Results comparable to this have been reported in the USA (Zhang et al. 2022), (Caglar and Mert 2022). Based on the GPR coefficient, we can infer that a 1% rise in GPR encourages a 0.216% decline in EF. Similar results have been reported for the world’s most resource-endowed nations (Mokni et al. 2022). Few potential explanations exist for these findings, either. For instance, the GPR rise causes the economy to grow more slowly, which reduces the EF. It is so because neighboring states’ and regional conflicts, increased political instability, and civil unrest work against long-term economic expansion. Reducing foreign direct investment, foreign trade, and international trade contribute to lessening environmental deterioration thanks to GPR.

The results found from multiple regression models (DOLS, FMOLS, AMG) have been cross verified by using the AMG robustness test. According to the test results economic growth, economic policy uncertainty, NREC and urbanization have a significant positive impact on EF, while RE and geopolitical risk have negative impact on EF in group of developed and developing countries. Our study outcomes are in line with study results of Syed and Bouri (2022a) and Caglar and Ulug (2022). While some research supports the use of renewable energy, other studies have found the opposite to be true. Canonical cointegrating regression (CCR) robustness test results shown in Table 9 endorse the above given regression results.

To check the consistency of results, this study employed canonical cointegrating regression (CCR) model as a robust estimation technique. The results of canonical cointegrating regression are presented in Table 9. The results show that the CCR model results are consistent with the previous estimation methods, i.e., FMOLS and DOLS.

It is important to understand not just the correlations between the explanatory variables but also the causal relationships between them, both in the long- and short-term. This research makes use of the (Dumitrescu and Hurlin 2012) published paired DH panel causality test. It is just a more sophisticated take on the Granger non causality test for panels. In addition, the F-statistic and the FDR-Q value are part of this method. When the q value is more than 0.10, the FDR demonstrates that no result rejects the null hypothesis. Once the direction of causality is established, policymakers in both rich and developing countries will be better able to implement effective economic and environmental policies.

According to the F-statistic, there is DH-panel causality between the variables. Table 10 provides a concise overview of the direction of causality in the D-H panel, classifying the relationships between the variables as unidirectional causality from right to left (\leftarrow), unidirectional causality from left to right (\rightarrow), no causality (\neq) and bidirectional causality (\leftrightarrow) when both variables Granger causes each other. The D-H panel causality test results indicate that LGDP and LEF (Li et al. 2023b), LREC and LEF, LURB and LEF, LEF and LEPU, LNREC and LGDP, LEPU and LGDP, LGPR and

LGDP, LREC and LNREC, LGPR and LNREC, LURB and LREC, LGPR and LREC, LEPU and LURB; and LURB and LGPR show unidirectional causality because of statistical significance referring to the rejection of the null hypothesis. This shows that economic growth, renewable energy consumption, urbanization, and economic policy uncertainty show unidirectional causality with ecological footprint; NREC, EPU, and GPR show unidirectional causality with economic growth (GDP); REC and GPR show unidirectional causality with NREC; URB and GPR show unidirectional causality with REC and economic policy uncertainty with urbanization; urbanization shows unidirectional causality with GPR. Furthermore, the D-H panel causality test shows bidirectional causality between LGPR and LEF; LURB and LNREC; and LGPR and LEPU which implies that GPR shows bidirectional causality with ecological footprint; urbanization shows bidirectional relation with NREC, and GPR shows bidirectional causality with economic policy uncertainty. However, no causal link was found between NREC to ecological footprint, renewable energy consumption to economic growth, urbanization to economic growth, and economic policy uncertainty to NREC and REC. However, the q values of FDR are reported in the fourth column to confirm the association between the variables. When q is greater than 0.10, FDR indicates that no result rejects the null hypothesis.

Discussion

The findings and their practical implications are discussed in this study section. Remember that EF is a measure of natural damage. However, because these economies are still in their formative stages, environmental concerns still need to be considered, as evidenced by the EKC's absence from this panel. The environment is deteriorating due to the present economic growth rate.

A high increase in EF requires a decrease in the level of EPU because increasing CO_2 emissions indicate rising building and consumption without limitations from economic policies. Our results corroborate those of Chen et al. (2022), who discovered a positive and significant connection between energy utilization, patents, R&D, and carbon emissions. Thus, the increasing rate of carbon emissions necessitates more ecological inventions to lessen the danger (Sun et al. 2022a).

Many researches have shown energy consumption as a critical factor in CO_2 emissions, although increases in energy requirement without turn-off to renewable energy sources—spikes carbon emission. Our results corroborate those of Wei et al. (2022b) and Huang et al. (2022), who found a favorable effect. Ultimately, RE's eco-friendliness means it can produce fewer greenhouse gas emissions.

Table 9 Canonical cointegrating regression (CCR) robustness test

Dependent variable (EF)	Coefficient	Std. err	P values
REC	-0.952	0.215	0.006
NREC	1.952	0.784	0.004
GPR	-0.664	0.125	0.002
LNEPU	0.277	0.037	0.000
GDP	1.854	0.455	0.005
URB	0.985	0.086	0.001

Table 10 Panel causality results

Variables	F-statistics	Decision on null hypothesis	FDR q -value	Direction
LGDP >> LEF	1.189*	Reject	0.05	LGDP→LEF
LEF >> LGDP	1.054	Accept	0.27	
LNREC >> LEF	0.576	Accept	0.18	LNREC≠LEF
LEF >> LNREC	1.189	Accept	0.45	
LREC >> LEF	1.543**	Reject	0.07	LREC→LEF
LEF >> LREC	1.654	Accept	0.34	
LURB >> LEF	3.056**	Reject	0.09	LURB→LEF
LEF >> LURB	0.543	Accept	0.66	
LEPU >> LEF	1.216	Accept	0.49	LEF←LEPU
LEF >> LEPU	2.754*	Reject	0.03	
LGPR >> LEF	3.523**	Reject	0.06	LGPR↔LEF
LEF >> LGPR	3.045*	Reject	0.04	
LNREC >> LGDP	1.848*	Reject	0.05	LNREC→LGDP
LGDP >> LNREC	0.349	Accept	0.59	
LREC >> LGDP	1.157	Accept	0.78	LREC≠LGDP
LGDP >> LREC	0.243	Accept	0.42	
LURB >> LGDP	1.535	Accept	0.54	LURB≠LGDP
LGDP >> LURB	0.754	Accept	0.67	
LEPU >> LGDP	2.057*	Reject	0.04	LEPU→LGDP
LGDP >> LEPU	1.256	Accept	0.34	
LGPR >> LGDP	1.043**	Reject	0.07	LGPR→LGDP
LGDP >> LGPR	0.067	Accept	0.41	
LREC >> LNREC	0.521	Accept	0.34	LREC←LNREC
LNREC >> LREC	5.176*	Reject	0.05	
LURB >> LNREC	4.647**	Reject	0.09	LURB↔LNREC
LNREC >> LURB	6.638*	Reject	0.04	
LEPU >> LNREC	0.317	Accept	0.38	LEPU≠LNREC
LNREC >> LEPU	0.854	Accept	0.45	
LGPR >> LNREC	0.216	Accept	0.78	LGPR←LNREC
LNREC >> LGPR	1.749*	Reject	0.03	
LURB >> LREC	1.512*	Reject	0.01	LURB→LREC
LREC >> LURB	1.176	Accept	0.52	
LEPU >> LREC	0.226	Accept	0.78	LEPU≠LREC
LREC >> LEPU	1.425	Accept	0.52	
LGPR >> LREC	2.764**	Reject	0.09	LGPR→LREC
LREC >> LGPR	1.767	Accept	0.27	
LEPU >> LURB	1.834**	Reject	0.09	LEPU→LURB
LURB >> LEPU	0.602	Accept	0.67	
LGPR >> LURB	1.216	Accept	0.45	LURB←LGPR
LURB >> LGPR	2.523*	Reject	0.05	
LGRP >> LEPU	2.176**	Reject	0.07	LGRP↔LEPU
LEPU >> LGRP	3.054*	Reject	0.03	

From our research, we learned that using renewable energy sources reduces pollution. These results bolstered Deev and Plíhal (2022) and Wu et al. (2022).

Most importantly, the data analysis confirms the scary impact of GPR on EF in China, with positive relationships

observed. To mitigate the severe impact of EF on environment, these results help strengthen China's financial and economic association with other inferring nations. Benkraiem et al. (2022) have examined how geopolitical instability threatens green ecological systems. Hence, China must

disentangle the competing motivations for consuming carbon-related products and services to facilitate trade, tourism, and globalization. Last but not least, according to China's recent records, the factor of natural resources has a positive and considerable association with EF. In addition, China's rapid industrialization and construction projects point to the intensive use of its few natural resources. Also, the significance level is low in the higher quartiles, rises steadily to its peak, and then falls back to earth again (0.40 and 0.70). As a result, CO₂ levels rise, and natural habitats deplete due to China's incessant exploitation of natural resources. In their research, Syed et al. (2021) show that the conventional method of harvesting natural resources is the root cause of ecological degradation. Current natural resource outputs and CO₂ emissions are supported by Shahzad et al. (2023). The empirical findings reveal a positive and statistically significant coefficient value for EPU. In the USA, the UK, Pakistan, China, and India, EF rise by 0.05%, 0.07%, 0.09%, 0.02%, and 0.05% for every increment of 1 EPU, respectively. It shows that more EPU means more environmental damage. Yilanci and Kilci (2021) lend credence to our empirical findings for France, whereas Abbas et al. (2022) provide direct opposition in the USA. An increase in UP also has a positive effect on ecological conditions. A 1% significance level indicates that UP's negative coefficient value is robust. Based on these calculations, the USA, the UK, and China would all see reductions in CO₂ emissions of 7.07%, 0.12%, and 0.61% for every 1% rise in EUP.

In comparison, Pakistan and India would see increases of 3.27% and 0.74%, respectively. It suggests that URB is viable in wealthy countries rather than in emerging ones. For the SAARC countries, Nguyen (2021) for the UAE, and Sun et al. (2022b) for Indonesia all corroborate these findings. Comparing our prediction to Liu et al. (2023) for 110 economies and Liu et al. (2022b) for MENA nations, we find that they are both off. Our results are consistent with those of the ecological modernization theory, which proposes that a high rate of urbanization is related to increased sustainability in cities. Urbanization leads to increased efficiency in the use of both labor and materials. In densely populated places, building and maintaining community services like waste management, water supply, hygiene, and several others are not high-priced. In addition, urbanization promotes modernization since it increases the prevalence of resource- and time-saving technologies and new forms of creative problem-solving (Sadiq et al. 2022). Short-term, both clean energy and URB are helping these nations produce less carbon dioxide. Furthermore, the consistency of our model is confirmed by the fact that the ECT has a significant and negative coefficient value for all of the countries chosen.

We discovered that the size of the impact of EPU varied by country, with high-pollution countries showing a

negative influence on carbon emissions during times of high EPU and low-pollution countries showing no such effect. To rephrase, the EPU can have a wide range of effects on carbon emissions. When economic policy is unknown, the effects of R&D, FDI, urbanization, and the use of RE on EF are mixed, with negative repercussions in low-pollution countries and positive benefits in high-pollution ones. Findings like this lend credence to the pollution haven hypothesis (PHH), which posits that countries with high pollution levels will attract people seeking refuge from it. However, Angiz and Keramatpour (2021) argue that the halo effect in low-pollution countries still exists, demonstrating the varied associations between carbon emissions and economic performance.

Conclusions and policy implications

Using the multiple econometric methods, the current research studied the influence of RE and economic policy uncertainties on CO₂ emissions in industrialized and emerging nations such as the USA, the UK, Pakistan, China, and India. In order to analyze the data more thoroughly, it was changed from annual to quarterly intervals. The URT with structural breaks supports diverse order of integration for both developing and developed nations. According to the DOLS, FMOLS, and AMG estimations, environmental quality declines in sample nations as economies expand and policy uncertainty increases. Nonetheless, the use of RE and the growth of cities are both excellent for the planet and help the selected countries maintain or even improve their already high environmental standards. In both Pakistan and India, urbanization has been increasing at highest rate. As this is the case, it is clear that both Pakistan and India need to upgrade their cities. It calls for the use of RE sources. More green space is needed in urban areas.

Based on our empirical research, increasing ecological innovation is necessary to reduce the ecological footprint to anticipate EPU, which could disrupt the success of emission reduction efforts. The rising level of carbon emissions, necessitates to expand the use of ecological innovations to curb it, including more investment in R&D and patent application filings and less reliance on nonrenewable energy sources. Most notably, we learned that there is a considerable variation in how EPU affects carbon dioxide emissions. Uncertainty strongly impacts the carbon emissions of countries with high pollution levels, but this is different for those with low pollution levels. Technological innovation, fossil fuel consumption, urbanization, and renewable energy sources (RE) all impact EF differently.

The findings also suggest that an improvement in environmental sustainability is associated with a 1% increase

in GPR. As an outcome of the negative effects of GPR on NREC and economic growth, CO₂ emissions have decreased. International trade, the stock market, energy costs, production, consumption, military tensions, war, and terrorism are all impacted by GPR. Additionally, GPR is the primary driver of investment decisions and has the potential to transform the financial and economic sectors in nations with stable governments and societies. Investment preferences may have shifted as a result of GPR, which could explain the decline in carbon dioxide emissions. Financial and economic sectors are strongly influenced by GPR because nations with unwavering societies and governments attract a great deal of FDI. It is possible that a change in investment priorities (caused by GPR) is responsible for the decline in carbon dioxide emissions. The negative effects of GPR on the environment are more pronounced in newly industrialized and developing nations, where they greatly outweigh any positive effects. Even though growing developed and developing nations have become the center of GPR and are gaining its economic benefits, GPR has had no impact on environmental deterioration in these regions. Our results are consistent with those from research conducted in Turkey by Hailiang et al. (2023), in the emerging stock markets of Asia by Zhou et al. (2023), in the BRICS countries by Ameer et al. (2023), in the USA by Syed and Bouri (2022b), and in 38 developing countries by Liu et al. (2022b).

Policy implications and further directions

The outcomes have some critical implications for public policy. First, policies should be open and unambiguous, and governments should use international treaties and summits to lessen economic policy ambiguity. All the global organizations, including WTO, the World Bank, and UNO, should take off initiatives to ease concerns about the future of economic policy. To do this, the government and the people may need to discuss reducing the negative socioeconomic impact of environmental regulations. Reducing EPU is a byproduct of effective communication between stakeholders. Moreover, urban areas should favor sustainable energy sources. It is time for legislators to reinforce their approach to urban planning. We need efficient use of technology to generate sustainable energy. It requires Pakistan and India to study the urbanization patterns of China, the USA, and the UK for guidance. Using fossil fuels as an energy source is pivotal in carbon emissions. Pakistan and India must switch to renewable energy sources instead of their current nonrenewable ones. The energy produced by these does not necessitate the use of fossil fuels. There should be tax breaks for using renewable energy sources the government provides. Investments in research and development need to grow. The provision of initiatives and funds for introducing innovation and

clean energy technology is also warranted. Import subsidies for RE sources should be made available. The panel data of emerging and wealthy countries can be compared in future studies.

The findings demonstrate that using renewable energy sources considerably mitigates environmental impacts. The need for more sufficient amounts of RE directly results from the costs involved in its production. More effort should be put into bolstering green financing aid in the renewable energy sector. While beneficial, renewable energy sources are now more expensive than fossil fuels, it means that the upfront cost of RE projects is high, and the payback period is lengthy. As a result, there is a pressing need to develop operational plans that integrate the growth of RE generation with the establishment of sustainable financial institutions. Introducing new regulations, such as reduced payments, simplified finance licenses, and quicker regulatory periods, can increase the supply of green credits for RE projects. Financial concessions, tax incentives, and the voluntary cancelation of loans are all examples of the favored forms of financing for the renewable energy industry. Finally, the expansion of renewable energy sources is necessary to reduce ecological footprint and it also reduces the impact of EPU and GPR on ecological footprint.

Our analysis of developing nations means that we can not make recommendations for advanced economies, which is one of the study's caveats. Second, the present investigation does not clarify the conclusions about the connection between GPRI and the environment on a country-by-country basis. Future studies can focus on examining the interplay between GPR and ecology in industrialized nations. The research could look at how GPR has an asymmetrical or non-linear effect on the natural world. GPR's direct and indirect effects on the natural world can also be investigated. In addition, the hypotheses concerning GPR, carbon emissions, and environmental deterioration can be tested using future prediction and structured machine learning panel data regression models.

Acknowledgements The project name: Zhejiang Province Philosophy and Social Science Planning project in 2022: comparative research on support policies and development models of entrepreneurial universities in China, Japan, and South Korea 22NDQN283YB

Author contribution Wang Jiatong: conceptualization, data curation, and methodology; Qi XU: conceptualization, data curation, and methodology; Muhammad Sibte-Ali: visualization, supervision, and editing; Farrukh Shahzad: writing—original draft and data curation; Bakhtawer Ayub: writing—review and editing and software.

Data availability The statistics supporting the outcomes of this research are accessible upon reasonable request from the first author.

Declarations

Ethical approval Not applicable.

Consent to participate Not applicable.

Consent for publication All authors have given consent to publish.

Competing interests The authors declare no competing interests.

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