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Does the causality between environmental sustainability, non-renewable energy consumption, geopolitical risks, and trade liberalization matter for Pakistan? Evidence from VECM analysis

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ABSTRACT

Geopolitical threats have increased dramatically globally in recent years, adversely affecting the environment tremendously. On the other hand, there is a growing gap between the use of non-renewable energy, trade liberalization, and environmental sustainability. Due to this, the current work simulates the links between geopolitical threats, non-renewable energy use, trade liberalization, and environmental sustainability using a vector error correction model (VECM) and Granger causality test. The analysis includes data spanning from 1980 to 2021. Research outcomes indicated that geopolitical risks (GPR), Non-renewable energy consumption (NRE), Natural Resource (NR) and industrialization (IND) have a negative and statistically significant influence i.e., 0.234, 0.052, 0.028, and 0.070 units respectively on environmental sustainability (ES) while natural resource (NR) have also negative but insignificant impact on environmental sustainability. Alongside, trade liberalization (TR) and urbanization (UB) posed a positive and statistically significant influence i.e., 0.040 and 0.437 units respectively on ES. Further, causality analysis validates the feedback effect among GPR, NRE, TR, and ES. GPR, NRE, and TR granger cause environmental sustainability. The government can prepare for potential environmental disasters such as floods, droughts, and earthquakes by investing in early warning systems, emergency response teams, and disaster relief supplies. This can help mitigate the impact of geopolitical risks that can result in natural disasters. Pakistan should prioritize investing large resources in diplomatic endeavours to improve regional dynamics and ties with neighboring nations. Pakistan should place a high emphasis on developing methods targeted at reducing its non-renewable energy use to mitigate the negative effects. This might entail offering financial incentives, implementing efficient feed-in tariff schemes, and developing a thorough strategy for boosting the capacity of renewable energy sources.

1. Introduction

Geopolitical risk (later as GPR) has emerged as a component of structural instability, attracting the interest of several scholars from many domains. Caldara and Iacoviello [1] describe GPR are possible political, economic, military, and social issues that arise because of a country's engagement in international events. They are common after a dramatic shift in power, a conflict, or a natural calamity. These risks have the potential to have far-reaching consequences for both the country and the whole global community. Many elements, including a country's economic stability, political connections with other countries, and military might, can all contribute to

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geopolitical hazards [2]. Globalization, through expanding the interconnection of the world's economy and cultures, has also contributed to the increase of these hazards in recent years. The argument suggests that GPR traits were associated with violence as well as warlike conduct. GPR are tensions between nations caused by extremism, conflicts, and unfavorable relations [3].

GPR could be having an impact on national productivity and investment portfolios, as well as generate market volatility that influences resource extraction revenues and the banking sector [4]. Due to uncertain geopolitical situations, investment spending is diverted to less profitable applications such as rehabilitation and military [5]. Moreover, catastrophic global tensions will excite investor and corporate concern, resulting in unexpected market changes and, ultimately, a negative influence on energy outcomes as well as instability [6]. As a result, global political risk is ranked among the top five global potential threats [7]. Geopolitical events have an impact on the economy, society, and the environment. Anser et al. [8] proposed novel ways for linking GPR and ecology. The first stream, dubbed the "escalating impact," shows how GPR decreases renewable energy consumption (hereafter REC), resulting in increasing CO_2 emissions. Furthermore, according to the "mitigating effect," GPR decreases nonrenewable energy consumption (later NRE) and economic development, resulting in lower CO_2 emissions [9].

Among the several variables recognized as key determinants impacting environmental sustainability, the roles of NRE and trade liberalization (later TR) should not be overlooked, especially when it comes to the increase of CO_2 emissions [10–12]. Empirical evidence suggests a substantial relationship between NRE and increasing CO_2 emissions [13–15]. TR holds the possibility of having both positive and negative impacts on environmental sustainability. On the one hand, it can allow cross-border exchange of environmentally friendly practices and information [16,17], while also fostering increased efficiency and innovation in industrial operations [18]. On the other hand, it can lead to increased resource consumption, pollution, and greenhouse gas emissions [19,20]. Therefore, the design and implementation of trade policies can play a significant role in promoting or hindering progress toward environmental sustainability. TR became a key engine of economic progress and development in the past few decades, but its impact on environmental sustainability has raised concerns [21–23]. To make sure that trade promotes rather than impedes the development of a more sustainable future, it is crucial to investigate the influence of TR on environmental sustainability as well as potential governmental interventions.

The global drive for sustainable development has resulted in an unprecedented increase in polluting sectors in recent years. According to Wang et al. [24], Dogan & Turkekul [25] industrialization significantly raises the amount of trade-embodied CO_2 emissions worldwide. Lin and Zhu [26] observed that rising industrialization lowers CO_2 emissions, albeit this might be due to modernization lowering economic reliance on agriculture, which would result in higher greenhouse gas emissions. The SDGs emphasize the need of making cities more live able, intelligent, resilient, healthy, and sustainable [27]. Green technology in the industrial process might aid in the reduction of CO_2 emissions. As a result of the greater use of green technology, this is being witnessed in some highly industrialized cities. The increased interconnection of world economies through trade, foreign direct investment, and international financial flows may aid the worldwide influence of these technologies. Despite increased demand for renewable energy, several nations continued to depend on fossil fuels [28] to accomplish the objective of high economic growth [29]. This increased usage of NRE contributes to the increase in CO_2 emissions and exerts negative pressure on environmental sustainability [30].

Following on from the preceding discussion, the primary goal of this study intends to investigate the effects of GPR, NRE, and TR on environmental sustainability. This study makes several kinds of contributions. Considering the case of Pakistan, for example, the earlier relationship of geopolitical concerns' influence on environmental sustainability is lacking. One key cause for this gap is Pakistan's strategic location in a region rife with geopolitical tensions and wars. Pakistan is located in a volatile region with ongoing conflicts and tensions with its neighboring countries. The ongoing conflict in Afghanistan and the rise of extremism in the region have made Pakistan vulnerable to security threats. Additionally, the long-standing tensions with India over the disputed territory of Kashmir have been a major source of instability in the region. The country also faces internal security challenges due to sectarian violence and the presence of militant groups. Pakistan faces significant challenges in terms of geopolitical risks and trade liberalization, but also has significant potential for renewable energy. Pakistan has a lot of opportunities for utilizing renewable energy sources, especially solar and wind power. Despite this potential, the country keeps depending significantly on non-renewable resources, particularly oil and gas. Additionally, as highlighted by Strezov et al. [31], the evaluation of sustainable development encompasses a wide set of indicators including economic, social, and environmental dimensions. Nevertheless, agreement on a single index to measure progress toward sustainable development remains difficult in both the political and scientific arenas. As Nourry [32] points out, the quest for a precise route towards attaining sustainable development remains a point of contention.

Lastly, I use Caldara and Iacoviello's freshly released GPR index (2018) [33]. Despite the importance and conclusions of prior research, proxies of geopolitical events having drawbacks in that they are not in real-time, are asynchronous and do not cover true geopolitical events. Yet, such proxies do not have to fully represent GPR because they do not contain all events, such as economic downturns, wars, and climate change [34,35]. This index is calculated from a monthly investigation of 11 major newspapers for articles about global events and conflicts. The index outperforms other measures because it gathers Data in a consistent, comprehensive, and real-time manner. Furthermore, the GPR index considers additionally up-to-date and potential threats [35].

2. Literature Review

2.1. GPR-environmental sustainability nexus

Recent research has focused on the complex link between GPR and its impact on energy use and environmental variables. Caldara and Iacoviello [33] have begun research on the relationship between GPR and rising energy use. Rasoulinezhad et al. [36] expanded on this investigation by discovering various factors that influence energy use. Their findings confirmed that GPR, CO_2 emissions, financial openness, and currency rates all have a favorable influence on energy use. Increase in Inflation, economic expansion, and population had a negative impact. Notably, a dynamic interaction with inverse causal linkages between population, CO_2 emissions, energy evolution, and economic expansion occurred. Arzova and Sahin [37] investigated the effect of GPR and financial growth on resource extraction (REC) in emerging economies. Their study was conducted in 19 countries, and they used GMM methodologies to demonstrate the favorable impact of GPR and financial development on the consumption of energy. Sweidan [38] analyzed the energy transmission networks of the United States, demonstrating that greater GPR is related to increased energy consumption, emphasizing the global character of this connection. Considering such results, Adam et al. [3] investigated the effects of economic policy uncertainty upon the use of nonrenewable energy (NRE) within resource-rich nations. Their research found that economic policy uncertainty along with GPR has a long-term impact on NRE. Adam et al. [3] used co-integration approaches to investigate the deep interconnections between CO_2 emissions, NRE, economic policy uncertainty, GPR, and growth. In the same way, Husnain et al. [39] conducted a comprehensive investigation of the multidimensional connection between economic policy uncertainty and its environmental consequences. Their research emphasized the ongoing negative impact of economic policy uncertainty on the e1nvironment, establishing a strong link between uncertainty and emissions. They further found a complex association where NRE, economic growth, and insecurity contributed to CO_2 emissions.

2.2. *Energy-environmental sustainability nexus*

A fundamental knowledge of the intricate dynamics of factors like the environment and energy usage has been made possible by this study. Mahalik et al.'s [40] research from 2021 examined the factors influencing CO_2 emissions in the BRICS nations between 1990 and 2015. The study investigated the influence of basic and secondary education on carbon emissions reduction in these countries. While basic education and NRE use led to increased emissions, secondary education, urbanization, and the use of resources all contributed favorably to improving environmental quality. In a similar line, Oke et al. [41] did a study concentrating on the link between renewable energy adoption and sustainable development in Africa from 1990 to 2015. The analysis showed that renewable energy reduces carbon dioxide emissions and promotes environmental quality. Adedoyin et al. [42] explored the impact of economic policy uncertainty on energy use, economic development, and emissions for 32 Sub-Saharan African nations between 1996 and 2014. Results indicated that the production of NRE and real GDP both increase CO_2 emissions. Sharif et al. [43] reviewed the effects of employing RE and NRE energy sources on Turkey's environmental effects. QARDL estimates that study parameters have significant negative signs for all quantiles. This outcome confirmed the long-run association between RE, NRE, and Turkey's environmental sustainability. Usman et al. [44] examines at how America's ecological footprint is affected by RE. The findings indicated a negative relationship between the ecological footprint and RE. NRE increases carbon pollution and the ecological footprint, whereas renewables decrease both. Zafar et al. [45] studied effects of abundant natural resources and the usage of RE on environmental quality in Asian nations between 1990 and 2018. According to the findings, increasing RE reduces carbon emissions and increasing the availability of natural resources improves environmental quality. Vo et al. [46] examined the relationship between energy, growth, and the environment in the OECD member countries by examining the influence of trade openness, financial development, and urbanization. According to the CS-ARDL findings, there is a bidirectional causal link between wealth, the proportion of renewable energy, and the proportion of NRE when it comes to CO_2 emissions. The research by Uddin et al. [47] looks at the effects of energy use, financial development, and economic growth on the ecological footprint of 119 developed and developing nations between 2002 and 2018. The findings demonstrate that the ecological footprint is favorably impacted in industrialized nations by elements such energy consumption, financial development, urbanization, globalization, foreign direct investment, and population expansion. However, the ecological footprint is significantly impacted in underdeveloped nations by the human development index, natural resources, and globalization. In order to manage their ecological footprints efficiently, both developed and developing countries need to have customized policy implications, according to the study.

2.3. *Trade-environmental sustainability nexus*

Qin et al. [12] investigated consumption-based carbon emissions (CBEs) in the Next Eleven (N-11) countries, aiming to address the gap in understanding their impact on climate change mitigation. Using the ARDL methodology, the study found that that imports play a greater role in CBEs whereas exports contribute less to CBEs both in the long term and short term. In eight Sub-Saharan African nations, between 1980 and 2014, the link between output, trade, renewable and non-renewable energy, and carbon dioxide emissions is examined by Vural [11]. Results indicated that while TR and NRE both raise carbon emissions, RE reduces them. Kolcava et al. [48], explored whether preferential trade agreements (PTAs) facilitate the shift of environmental burdens from developed to poorer countries. Results showed that trade liberalization enhanced the circulation of environmentally integrated commodities. Khan et al. [49] evaluated the influence of trade on G7 CBEs emanations. CO_2 emissions, revenue, commerce, renewable energy, and innovative environmental technologies are all cointegrated, according to the statistics. Trade and income had a substantial beneficial impact on consumer-based CO_2 emissions, but ecological development, exports, and renewable energy use have a negative impact. Wang and Ang [50] evaluated the effects of international trade on global CO_2 emissions from 1995 to 2009. The study found that while trade volume increased emissions, changes in emission intensity and goods composition led to some mitigation, especially after 2005. Liddle [51]in his study found that imports increase carbon emissions for territorial and consumption-based emissions. GDP has been found to raise emissions from both ends, with fossil fuel consumption and the manufacturing component of GDP both increasing and decreasing pollutants. Shahbaz et al. [51] investigated the link between foreign direct investment (FDI) and carbon emissions in the Middle East and North Africa from 1990 to 2015. They study found evidence that trade openness degrades environmental quality worldwide, high-income, middle-income, and low-income groups all get affected.

3. Methodology

3.1. Conceptual framework

In the below-mentioned Fig. 1, it is suggested that trade liberalization, non-renewable energy, and geopolitical risk are all related to environmental sustainability. When faced with geopolitical concerns, countries prefer renewable energy sources to reduce their dependence on fossil fuels. This shift could lead to more sustainable environmental practices. Geopolitical conflicts may also have a negative impact on the environment through the loss of natural ecosystems and pollution brought on by war. The usage of Non-renewable energy is depicted to have negatively impact on environmental sustainability. Burning fossil fuels such as coal, oil, and natural gas results in emissions that contribute to greenhouse gas emissions, pollution, and acid rain. This can lead to climate change, ecosystem disruption, soil and water degradation, and negative impacts on human health. Furthermore, the extraction and transport of non-renewable energy sources can cause damage to ecosystems and wildlife habitats [52].

Trade liberalization has two distinct impacts for environmental sustainability. On the one hand, its adoption causes an increase in output and consumption, which may have negative environmental consequences such as increased carbon dioxide, methane, and nitrous oxide emissions. Furthermore, trade expansion may promote the depletion of natural resources, deforestation, and habitat obliteration, posing dangers to biodiversity and jeopardizing the long-term sustainability of ecosystems. Nevertheless, it is critical to recognize that increased trade can result in beneficial effects. Trade liberalization can enable governments to play a more effective role in environmental management by boosting economic growth, supporting development, and improving social well-being. Equally important is the potential for open markets to promote access to breakthrough technology, improving local manufacturing processes and reducing the consumption of natural assets such as energy, water, and other ecologically harmful elements.

3.2. Variable description and data sources

The current research aimed to investigate the Causality between environmental sustainability, geopolitical risks, and trade liberalization in the case of Pakistan. The selected dataset includes significant variables such as GPR, TR, NRE, NR, UB, and IND, all of which contribute to a thorough investigation. GPR, which represents potential political, economic, military, and social risks that can emerge from a nation's involvement in international affairs, is based on studies by Husnain et al. [39]. Meanwhile, TR, which represents the removal or reduction of barriers to the free movement of products between nations, is based on the comprehensive study undertaken by Khurshid et al. [53]. NRE is based on the incisive work of Li and Haneklaus [54] and provides an approximate approximation of fossil fuel energy use as a fraction of overall consumption. Similarly, Tufail et al. [55] generated NR, which is approximately calculated as total natural resource rents as a proportion of GDP. The UR parameter, which represents the urban population proportion compared to the overall population as well as industrialization, is based on painstaking research by Khurshid et al. [56]; Saqib & Dinca [57]. Our data's temporal scope spans the years 1980–2021, allowing for a full and extensive examination. More information about the data and the sources used may be found in the informative Table 1 shown below.

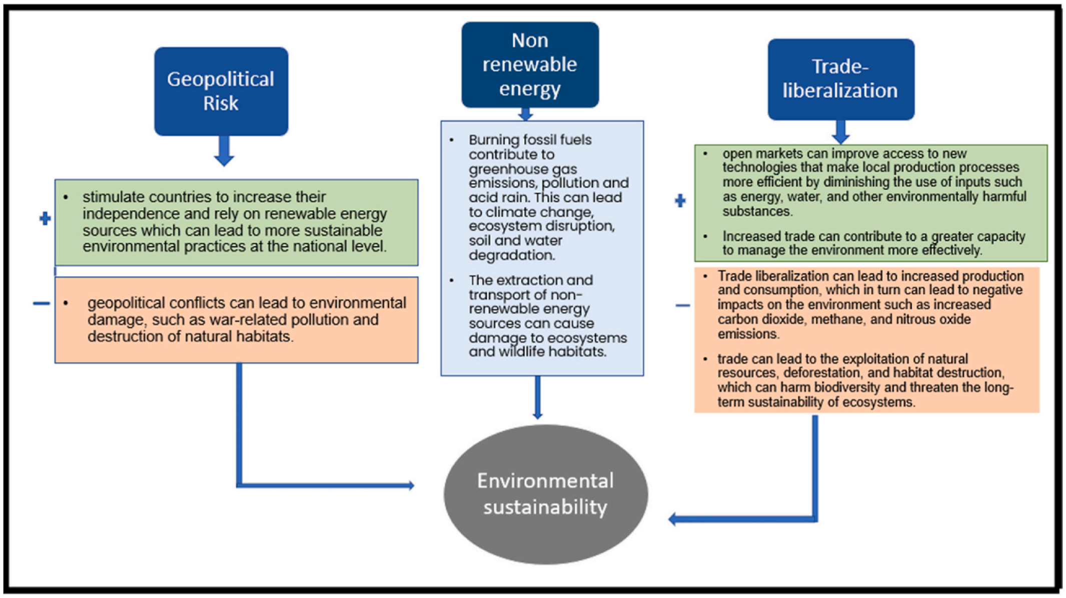

Fig. 1. Transmission mechanism of study variables (Authors 'Creation based on Literature Review).

3.3. Model specification

Pakistan is geographically located in a region that has long been plagued by political unrest. With Afghanistan and Iran on its western border, both of which are effectively cut off from the international system, and a fragile relationship with India on its eastern border, Pakistan must traverse treacherous territory. This is worsened by escalating rivalry between the US and Pakistan's northern neighbor, China. To achieve its development objectives while navigating the turbulence, the government must secure internal security, strengthen its economy, and seek regional peace. Increasing geopolitical tensions between major countries such as the United States, China, and Russia have raised fears that Pakistan would be compelled to take a side. Pakistan's geostrategic position holds it back due to hostile relations with neighboring nations and the region's ongoing instability.

As a result, the primary goal of the current study aims to figure out the relationship between ES, GPR, TR, and NRE. The subsequent model was put together for achieving the goal of the present research.

$$\mathrm{ES} = \mathrm{f(GPR, NRE, IND, TR, NR, UB)} \tag{1}$$

To explore the long-run relationship among study variables, Eq. (1) is expanded in the following form (see Eq. (2)):

$$ES_t = \omega_0 + \omega_1 GPR_t + \omega_2 NRE_t + \omega_3 IND_t + \omega_4 TR_t + \omega_5 NR_t + \omega_6 UB_t + \in_t \tag{2}$$

3.4. Causal relationship testing

For the examination of the existence of a causal relationship between study variables, the Granger Causality method was used. To clarify the procedure of assessing Granger causality, the following models in the form of Eq. (3) and Eq. (4) are considered:

$$Y_t = \sum\nolimits_{i=1}^{p} a_i Y_{t-i} + \sum\nolimits_{i=1}^{p} b_i X_{t-i} + \mu_t \tag{3}$$

$$X_t = \sum\nolimits_{i=1}^{p} a_i X_{t-i} + \sum\nolimits_{i=1}^{p} b_i Y_{t-i} + \mu_t \tag{4}$$

3.5. Long-run relationship testing

3.5.1. Johansen Cointegration test

Johansen Cointegration used the Maximum Eigenvalue test and Trace test to determine the number of cointegration vectors. For r = 0, 1, 2, …, n-1, the greatest eigenvalue compares the null hypothesis of r cointegrating relations to the alternative of r+1 cointegrating relations. These test statistics can be computed in the form of Eq. (5):

$$\lambda_{trace} = -T \sum_{i=r+1}^{K} \log\left(1 - \lambda_i\right) \tag{5}$$

Where λ is the maximum Eigenvalue and T is the sample size. Trace statistics investigate the null hypothesis of r cointegrating relations against the alternatives of n cointegrating relations where n is several variables in the system of r = 0, 1, 2, …, n-1. The following Eq. (6) is used for the maximum eigenvalue test:

$$\lambda_{max} = -T log(1 - \lambda_{r+1}) \tag{6}$$

3.6. Short-run dynamic testing

The VAR model is a statistical model that assumes each endogenous variable in the system to be the system's lagged value. The autoregressive distributed lag model can be used to develop the error correction model if there is a co-integration relationship between

Table 1
Description and definition of variables.

Variables	Symbols	Remark/comment	Data source
Environmental Sustainability	ES	The sustainable development Index was built by using, economic (GDP), Social (Life expectancy), and Environmental (Ecological Footprint) aspects of sustainable development	WDI, Global Footprints Network
Geopolitical Risks	GPR	Index	https://www.matteoiacoviello.com/gpr.htm
Non-renewable energy consumption	NRE	Fossil fuel energy consumption (% of total)	WDI
Industrialization	IND	Manufacturing, value added (% of GDP)	WDI
Trade Liberalization	TR	Trade globalization index	Koff index
Natural Resources	NR	Total natural resources rents (% of GDP)	WDI
Urbanization	UB	Urban population (% of the total population)	WDI

the variables. The VEC model can be viewed as a VAR model with cointegration constraints, as it includes a wide variety of short-term dynamic fluctuations. Given that the VEC model includes a wide variety of short-term dynamic fluctuations, VEC expressions can restrict the long-term behavior of endogenous variables and be convergent to their cointegration relation.

Assuming that $Y_t = (Y_{1t}, Y_{2t}, \ldots, Y_{kt})$ as k-dimensional stochastic time series, t = 1,2, …., T and $y_{it} \sim I(1)$, each $y_t \sim I(1)$, i = 1, 2, …, k is affected by exogenous time series of d-dimension $(x_t = x_{1t}, x_{2t}, \ldots, x_{dt})^{/}$, then the VAR model can be written in the form of Eq. (7):

$$y_t = A_1 y_{t-1} + A_2 y_{t-2} +, \ldots, A_m y_{t-m} + Bx_t + \mu_t \tag{7}$$

where, t = 1,2, …., T.

If y_t is not affected by exogenous time series of d-dimensions $(x_t = x_{1t}, x_{2t}, \ldots, x_{dt})^{/}$, then the VAR model of eq. (7) can be written as (see Eq. (8)):

$$y_t = A_1 y_{t-1} + A_2 y_{2-1} +, \ldots, A_m y_{t-m} + \mu_t \tag{8}$$

With the cointegration transformation of formula (8), we can write as (see Eqs (9)–(11)):

$$\Delta y_t = \Omega y_{t-1} + \sum_{i=1}^{m-1} \Pi_i \Delta y_{t-i} + \mu_t \tag{9}$$

where

$$\Omega = \sum_{i=1}^{m} A_i - I \tag{10}$$

$$\Pi_i = \sum_{j=i+1}^{m} A_j \tag{11}$$

If y_t *has* cointegration relationship, then $\Omega y_{t-1} \sim I(0)$ and formula (9) can be written in the form of Eq. (12):

$$\Delta y_t = \alpha\beta^{/} y_{t-1} + \sum_{i=1}^{m-1} \Pi_i y_{t-i} + \mu_t \tag{12}$$

Where, $\alpha\beta^{/} y_{t-1} = ecm_{t-1}$ is the error correction term, which reflects the long-term equilibrium relationship between variables, and the above formula can be written in the form of Eq. (13):

$$\Delta y_t = \alpha ecm_{t-1} + \sum_{i=1}^{m-1} \Pi_i y_{t-i} + \mu_t \tag{13}$$

4. Results and discussion

4.1. Descriptive statistics

Table 2 displays descriptive stats for the variables being studied. The table outcome shows that the mean score of ES is 0.000 with a minimum score of −1.380 and a maximum of 2.020. The mean score of IN, TR, RE, LGPR, NR, and UB is 13.454, 32.138, 51.215, 1.908, 1.319, and 32.905 respectively. NRE has the highest standard deviation value while LGPR has the lowest Standard deviation value. ES, TR, NR are positively skewed while LGPR, NRE, IND and UB are negatively skewed. Descriptive statistics further showed that almost all variables are platykurtic. The summary statistics of Jarque-Bera show that all variables except TR have a normal trend.

Table 2
Descriptive statistics.

	ES	LGPR	TR	NRE	IND	NR	UB
Mean	0.000	1.908	32.138	51.215	13.454	1.319	32.905
Median	−0.240	1.925	29.670	54.230	13.705	1.145	33.080
Maximum	2.020	2.130	40.860	62.480	15.710	2.620	37.440
Minimum	−1.380	1.600	26.720	35.290	10.220	0.730	28.070
Std. Dev.	1.000	0.112	4.884	8.858	1.553	0.547	2.738
Skewness	0.470	−0.504	0.550	−0.518	−0.502	0.917	−0.110
Kurtosis	2.073	3.358	1.792	1.785	2.140	2.572	1.850
Jarque-Bera	3.054	2.003	4.671	4.461	3.062	6.201	2.400
Probability	0.217	0.367	0.097	0.107	0.216	0.045	0.301

4.2. Correlation among variables

The Correlation matrix corresponding to the study parameters is provided in Table 3. The outcome of the estimation unveils those study parameters like IND, TR, NRE and NR have a positive association with environmental sustainability while LGPR and UB have a negative association. This signposts that a unit upsurge in IND, TR, NRE, and NR increases environmental sustainability by 0.363, 0.125, 0.183, and 0.142 units respectively. However, LGPR and UB are found to be harmful to ES by −0.205 and −0.082 units respectively.

Before we can estimate our empirical model, we must first confirm that our variables are stable. To assess stationarity, we are currently using the Augmented Dickey-Fuller (ADF) and Phillip Perron (PP) tests. Table 4 presents the ADF and PP findings. The test findings indicate that all of our study parameters are of integration of order one, i.e., I(1). We were able to examine the long-run equilibrium linkages between variables utilizing this mixed degree of integration by applying the Johansen cointegration test (1988).

We examined the study series for the presence of a single unknown breakpoint using the Zivot and Andrews [58] test. The results of Zivot-Andrews tests are presented in Table 5. Except for GPR, the results of this research demonstrated that all variables display stationarity at the first difference. This observation alludes to the series' same levels of integration. This additional test strengthens the validity and dependability of our findings.

4.3. Empirical results

The VAR model is used to calculate lag duration requirements after examining the amount of stationarity among research parameters. The suitable lag must be chosen since it offers a picture of the total number of times required for a data parameter to respond to changes in other parameters. Table 6 displays the results of determining the required leg length. Thus, it can be concluded that the as per AIC Criteria, optimum lag 2 is more appropriate for the VECM model.

Following uncovering the lag length, the Johansen maximum likelihood technique is employed to figure out if the variables in study have a long-run interaction. The analyses' findings are shown in Table 7, which compares the co-integration alternative to the null hypothesis of no co-integration using both maximal-eigen value statistics and trace statistics. The generic alternatives of 7 and 4 co-integrating links, respectively, are significantly preferred by the trace and max statistics over the null hypothesis of no co-integration at the 5 % level of significance. Since the variables in study show a balanced relation and movement similarity over time, it is possible to argue that at least one type of cointegration equation exists. In the phase that follows, we may run the long-term parameters using the VECM technique after determining the cointegration between the variables.

The short-run results are shown in the lower panel of Table 8. The "speed of adjustment" coefficient for the error correction component is negative, which is advantageous since it denotes convergence to the long-run equilibrium. In this case, the adjustment term suggests that the current year's deviations from long-run equilibrium are offset at a rate of 0.39%. Both the t-statistics of the regressor and the error correction term need to be significant to infer a meaningful causal influence in the VECM. The top half of Table 7 displays the normalized coefficients of the cointegrating vector's long-run performance. The equation for normalized coefficients is as follows:

$$ES+0.070(IND)-0.040(TR)+0.052(NRE)+0.234(LGPR)+0.028(NR)-0.437(UB)$$

To make ES an endogenous variable, the above equation is modified in the following form:

$$ES=-0.070(IND)+0.040(TR)-0.052(NRE)-0.234(LGPR)-0.028(NR)+0.437(UB)$$

The long-run results depict that INS, NRE, LGPR, and NR affect environmental sustainability while TR and UB impact positively environmental sustainability.

Given the proclivity of environmental degradation and climate change to cause geopolitical disagreements and wars, there is a strong relationship between environmental sustainability and geopolitical threats. Furthermore, trade liberalization has a bearing on both environmental sustainability and geopolitical dangers. Expanding trade promote economic growth and progress, but it also puts more pressure on the environment. This scenario, however, provides an opportunity for nations to collaborate and participate in environmental preservation endeavours, since failing to fulfill expected environmental criteria may result in limited market access. Considering these links, the investigation digs into the impact of GPR., TR and NRE on ES by using Johnsen's cointegration approach. The long-run results depict that UB and TR are positively and significantly correlated with environmental sustainability while GPR,

Table 3
Correlation matrix.

	ES	LGPR	TR	NRE	IND	UB	NR
ES	1						
LGPR	−0.305	1					
TR	0.740	−0.121	1				
NRE	0.900	−0.319	0.740	1			
IND	−0.543	−0.062	−0.295	−0.561	1		
UB	0.962	−0.340	0.736	0.975	−0.544	1	
NR	0.341	0.015	0.753	0.507	−0.089	0.437	1

Table 4
Unit Root test Results of Series.

PP(Prob.)			ADF (Prob.)	
	I(0)	I(1)	1(0)	I(1)
	Without Trend	Without Trend	Without Trend	Without Trend
ES	1.00	0.00	1.00	0.00
NRE	0.21	0.00	0.20	0.00
GPR	0.26	0.00	0.26	0.00
TR	0.64	0.00	0.58	0.00
IND	0.32	0.00	0.33	0.00
UB	0.21	0.02	0.99	0.03
NR	0.48	0.00	0.51	0.00

Table 5
Zivot-Andrews Structural Break Unit Root test Results.

	I(0)		I(1)	
	t-stat	Break Points	t-stat	Break Point
ES	−2.606	1997	−5.090**	2003
GPR	−5.316*	2001	−5.401***	2004
TR	−8.058	2005	−9.004***	2007
RNE	−4.741	1995	−7.071*	1987
NR	−5.685	2005	−6.791**	2013
UR	−5.332	1999	−10.583**	1991
IND	−2.238	2000	−6.612**	2009

Table 6
Lag length criteria.

Lag	LogL	LR	FPE	AIC	SC	HQ
0	−284.1	NA	0.004942	14.555	14.8506	14.66189
1	79.5358	581.818	7.55E-10	−1.1768	1.187644*	−0.321884*
2	134.416	68.59984*	7.09e-10*	−1.470781*	2.96253	0.132163

Table 7
Johansen Co-integration test results.

Hypothesized	Trace Statistics		0.05	Max-Eigen		0.05
No. of CE(s)	Statistic	Critical Value	Prob.[b]	Statistic	Critical Value	Prob.[b]
None[a]	244.159	135.615	0.000	79.331	47.451	0.000
At most 1[a]	164.828	98.754	0.000	52.878	43.078	0.001
At most 2[a]	111.950	71.819	0.000	44.531	35.877	0.002
At most 3[a]	67.419	48.856	0.000	29.711	28.584	0.026
At most 4[a]	37.708	29.797	0.005	19.392	22.132	0.086
At most 5[a]	18.316	15.495	0.018	13.945	14.265	0.056
At most 6[a]	4.371	4.874	0.037	4.371	3.841	0.037

Trace test and Max-eigenvalue indicate 7 and 4 cointegrating eqn(s) at the 0.05 level respectively.
[a] *denotes rejection of the hypothesis at the 0.05 level.*
[b] *MacKinnon-Haug-Michelis (1999) p-values.*

NRE consumptions and IND have significantly negative impact on ES while NR have an insignificant negative association with Environmental sustainability.

According to our research findings, a unit rise in GPR results in a significant increase of 0.234 units in ES. Surprisingly, our findings are consistent with the findings of Wang et al. [59], validating the complex link between geopolitical threats and their influence on environmental sustainability. There is a lot of research in the current body of literature that offers persuasive evidence about the influence of uncertainty on key economic performance metrics. In theory, uncertainty has a restricting effect on economic activity, appearing as a reduction in investment, consumption, borrowing, and hiring. Furthermore, it limits the efficacy of fiscal and monetary policies, as demonstrated by Caldara and Iacoviello [33] and Rasoulinezhad et al. [36].

Findings further reflect that TR has a positive and significant association with ES i.e., one unit increase in TR increases the ES by 0.040 units. Our findings are consistent with those of Hu and McKitrick [60], who discovered that trade liberalization improves local

Table 8
Results of VECM model.

Variable	Co-efficient	Std.Error	t-stat
Long Run Results			
LGPR(-1)	0.234	−0.089	2.628
TR(-1)	−0.040	−0.004	−11.014
NRE(-1)	0.052	−0.004	12.510
IND(-1)	0.070	−0.007	9.746
NR(-1)	0.028	−0.032	0.871
UB(-1)	−0.437	−0.015	−28.317
Short Run Results			
CointEq1	−0.390	−0.175	2.227
D(GPR(-1))	−0.120	−0.177	−0.678
D(GPH(-2))	0.045	−0.107	0.418
D(TR(-1))	0.017	−0.008	2.133
D(TR(-2))	0.013	−0.008	1.773
D(NRE(-1))	0.015	−0.012	1.234
D(NRE(-2))	−0.012	−0.013	−0.981
D(IND(-1))	0.005	−0.011	0.400
D(IND(-2))	−0.003	−0.016	−0.178
D(NR(-1))	−0.058	−0.041	−1.433
D(NR(-2))	−0.050	−0.036	−1.404
D(UB(-1))	−1.479	−1.049	−1.410
D(UB(-2))	−1.539	−0.764	−2.014
C	0.866	−0.312	2.774

output while decreasing the consumption of ecologically damaging items. The findings back up the pollution haven idea. Moreover, Awan et al. [61] have shown that trade may contribute to environmental sustainability by boosting knowledge of environmentally friendly technologies.

Our results also indicate that NRE usage has a significantly negative impact on ES. A one-unit increase in NRE use worsens ES by 0.052 units. This could be a result of the push to increase domestic output using new technology, energy consumption grows, reducing environmental sustainability. In Pakistan, NRE includes coal usage, natural gas consumption, and oil consumption. The majority of these NRE resources are utilized for commercial activities that affect the environment by generating CO_2. The findings are supported by Adedoyin et al. [42], Saqib et al. [62], Alam et al. [63] and Sharif et al. [43]. According to prior studies, the extraction of NRE natural resources causes pollution and decreases environmental quality by increasing CO_2 emissions.

Study outcomes show that one unit increase in IND leads to a reduction in ES by 0.070 units. The environmental impact of the industrial revolution is widely acknowledged to be detrimental, with increasing output in inefficient and greenhouse gas emitting companies such as the plastics industry taking off during the industrial revolution. For instance, the recent emergence of the plastic industry suggests that throughout the early stages of the industrial revolution, not only have emissions increased but also a requirement of mass manufacturing and the accumulation of waste products. Because there is an excessive amount of waste in landfills, single-use products, single-use plastics, and mass manufacturing have increased greenhouse gas emissions. As a result, our findings are strikingly comparable to past research, which shows that industrialization has a detrimental impact on the environment [64–68]. They conclude that as businesses grow, economies access to snipping and environmentally friendly technologies become much more controllable, and thus their involvement in environmental damage gradually decreases, is supported by a long-lasting adverse connection between industrial growth and air pollution. Further, According to Pan et al. (2019), and Khurshid et al. (2023b) [69,70], the modernization process relates to increased energy use. As a result, industrial operations may result in air pollution and environmental deterioration.

NR, on the other hand, hurt the ES by 0.028 units. Natural resources are extracted from the environment and typically changed or generated before being utilized to produce the final commodities and services that humans make and consume. Unsustainable consumption and production practices are to blame for the world's three major disasters: global warming, habitat destruction, and environmental harm. Climate change is caused by using fossil fuels such as coal, oil, and gas to power business operations. It is additionally brought about by the mining and manufacturing of certain materials, each of which might generate greenhouse gases. The supply of agricultural and nutritional items contributes significantly to greenhouse gas emissions due to the usage of nitrogen-rich fertilizers. Furthermore, methane-emitting livestock production and deforestation for agricultural cultivation and animal grazing put further burden on environmental sustainability. These linked dynamics are fueling the rise of three major global concerns, all of which are exacerbated by the accompanying environmental toll.

We discovered a favorable and statistically significant association between UB and ES during our research. This discovery is consistent with the findings of Dogan and Seker [71]. These scholars argue that the adverse impacts of pollution aren't naturally irreversible; instead, they ought to put forward that environmental challenges arising from industrial processes or energy consumption in urban areas can be mitigated by strengthening environmental regulations, technological innovations, and structural changes. Researchers such as Chen et al. [72] and Liddle [73] argue that greater urbanization density allows for better utilization of public infrastructure, resulting in lower energy consumption and emissions. Carefully designed urbanization projects, particularly those focusing on mobility, can reduce both greenhouse gas emissions and air pollution. The inclusion of extensive public transport networks is beneficial, and the construction of smaller, well-designed cities can help to reduce commuting distances [74]. Nevertheless, it is important to note that our findings contradict those of Rakshit et al. [75], who argue that urbanization contributes to environmental deterioration. This disparity highlights the complex nature of the urbanization-environment link, as well as the need to consider the numerous elements impacting environmental consequences.

The cointegration analysis implies that each of the indicators has a long-term equilibrium relationship, but more studies must be conducted to determine the causative relationship. If parameter A is beneficial for forecasting B, that is, if the regression of B is determined by prior values of B and prior values of A are included, the explanatory capacity of the regression can be greatly boosted. It is the non-Granger cause if A is the Granger cause of B. The P value should be less than 5 %, indicating that the null hypothesis (the presence of the Granger causation) must be accepted. Table 9 shows that most variables exhibit unidirectional causation. Granger causality results indicate that GPR causes ES through unidirectional causality. Political, economic, and social issues can destabilize areas, disturb international connections, and halt economic activity [76]. Governments and corporations may prioritize security and economic stability when tensions mount, diverting focus away from environmental sustainability programs [77]. This is especially problematic since long-term planning and investment in sustainable energy projects, climate change mitigation, and conservation may suffer [78–80]. The direct influence of geopolitical threats on policy decisions, resource allocation, and economic goals, rather than the opposite causal relationship, accounts for the unidirectional causation between geopolitical risks and environmental sustainability.

To assess the model's heteroskedasticity, serial correlation autocorrelation, and normalcy, diagnostic tests were run. The p-value from the LM test, which was bigger than 0.05, suggests that there may not be any serial correlation between the variables. The data is regularly distributed, as evidenced by the positive and significant Jarque-Bera test result of 116.932 (according to the normality tests). The findings of Table 10 shows that there is no heteroskedasticity because the $P = 0.335$ is larger than the 5 % level of significance.

The Cholesky impulse response function is a useful analytical instrument for determining how periodic shocks affect endogenous variables. It aids in determining the changing behavior of shock impacts as time passes, hence improving our grasp of complicated relationships. Table 11 reveals commonalities in how shocks rebound through variables such as GPR, IND, NRE, TR, NR, and URB. GPR and NR have a beneficial effect on the ES after a second-phase one-unit shock, but influence of TR and IND consistently dies down throughout 10 periods. The influence of URB dies down until the 9th period, then it turns positive by the 10th period. The NRE's impact on the ES dies down until the seventh period then it turns positive.

Table 12 extensively explains the variance decomposition study's findings. According to our findings, the most significant variation in ES is caused by GPR which accounts for 20.7 %. Moreover, trade liberalization emerges as another important component, accounting for 14.2 % of the variability, closely followed by the role of natural resources at 13.13 %. The significance of these characteristics in establishing environmental sustainability is demonstrated by their large effect on overall system volatility.

4.4. Conclusion

During the turn of the century, the world saw periods of elevated geopolitical risk (GPR), trade liberalization, and concomitant energy demand. These three parameters influence not just macroeconomic metrics but also environmental sustainability. Pakistan has experienced a difficult geopolitical atmosphere since its independence, with chronic security worries, bad relations with important allies, and economic challenges. Pakistan has faced several security difficulties, including terrorism, sectarian bloodshed, and separatist movements in various parts of the country. With problems in Afghanistan, Iran, and the Middle East, Pakistan is in a dangerous zone. Insecurity in neighboring nations may spread to Pakistan, putting its security and stability at risk. Nonetheless, tensions have remained high between Pakistan and India, notably over the disputed territory of Kashmir. Both nations have accused one other of supporting terrorism, resulting in military skirmishes and the fear of war. Apart from geopolitical challenges, Pakistan's physical location makes it a vital regional center connecting South Asia to Central Asia, the Middle East, and beyond. As a result of increased

Table 9
Pair wise granger causality test.

Null Hypothesis:	F-Statistic	Prob.
LGPR # ES	2.625	0.087
ES # LGPR	0.787	0.463
NRE # ES	4.767	0.035
ES #NRE	0.803	0.501
URB # ES	3.546	0.040
ES # URB	0.507	0.607
TR # ES	3.013	0.062
ES # TR	0.078	0.925
NRE # IND	3.075	0.059
IND # NRE	0.849	0.437
LGPR # IND	2.712	0.080
IND # LGPR	4.552	0.018
URB # IND	3.362	0.046
IND # URB	0.345	0.711
URB # NRE	0.086	0.918
NRE # URB	9.057	0.001
URB # NR	2.115	0.136
NR # URB	2.931	0.067

Table 10
Results of diagnostic tests.

Panel A: Serial correlation LM Test			
Lag	LM stat	d.f.	Prob.
1	30.768	49	0.981
2	0.539	49	0.985
Panel B: Normality Test			
Statistic	χ 2	d.f.	p-Value
Skewness	32.547	7	0.000
Kurtosis	84.386	7	0.000
Jarque-Bera	116.932	14	0.000
Panel C: Panel C: Heteroscedasticity Test			
White	χ 2	d.f.	p-Value
Statistics	856.916	840	0.335

Table 11
Response of ES.

Period	ES	GPR	TR	IND	NR	URB	NRE
1	0.048	0.000	0.000	0.000	0.000	0.000	0.000
	(-0.005)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
2	0.037	0.014	−0.008	−0.009	0.006	−0.011	0.003
	(-0.011)	(-0.009)	(-0.010)	(-0.009)	(-0.009)	(-0.009)	(-0.009)
3	0.042	0.033	−0.017	−0.006	0.009	−0.003	0.000
	(-0.012)	(-0.012)	(-0.012)	(-0.010)	(-0.010)	(-0.010)	(-0.010)
4	0.044	0.036	−0.027	−0.014	0.021	−0.011	0.002
	(-0.015)	(-0.016)	(-0.015)	(-0.014)	(-0.015)	(-0.013)	(-0.013)
5	0.050	0.036	−0.029	−0.014	0.027	−0.010	−0.002
	(-0.017)	(-0.019)	(-0.019)	(-0.017)	(-0.019)	(-0.015)	(-0.016)
6	0.051	0.033	−0.032	−0.016	0.032	−0.012	−0.001
	(-0.019)	(-0.022)	(-0.023)	(-0.020)	(-0.022)	(-0.017)	(-0.019)
7	0.053	0.032	−0.031	−0.015	0.032	−0.007	−0.001
	(-0.020)	(-0.023)	(-0.025)	(-0.023)	(-0.025)	(-0.018)	(-0.020)
8	0.052	0.030	−0.031	−0.014	0.032	−0.005	0.001
	(-0.021)	(-0.024)	(-0.027)	(-0.024)	(-0.027)	(-0.019)	(-0.022)
9	0.051	0.030	−0.030	−0.013	0.030	−0.001	0.003
	(-0.021)	(-0.023)	(-0.028)	(-0.025)	-(0.028)	(-0.020)	(-0.022)
10	0.049	0.030	−0.029	−0.012	0.029	0.001	0.005
	(-0.022)	(-0.022)	(-0.029)	(-0.025)	(-0.028)	(-0.021)	(-0.023)

Table 12
Variance decomposition of ES.

Period	S.E.	ES	GPR	NRE	TR	IND	NR	URB
1	0.048	100.000	0.000	0.000	0.000	0.000	0.000	0.000
2	0.065	88.211	4.863	0.282	1.479	1.736	0.779	2.650
3	0.086	73.248	17.399	0.160	4.537	1.545	1.450	1.662
4	0.110	60.618	21.218	0.134	8.963	2.611	4.419	2.036
5	0.134	55.445	21.811	0.113	10.759	2.915	6.978	1.978
6	0.155	52.311	20.718	0.086	12.174	3.292	9.391	2.028
7	0.173	51.053	19.861	0.072	12.940	3.331	10.955	1.788
8	0.189	50.181	19.180	0.065	13.553	3.373	12.083	1.565
9	0.203	49.767	18.829	0.076	13.923	3.317	12.728	1.360
10	0.216	49.423	18.639	0.131	14.214	3.244	13.136	1.213

economic activity and geopolitical risk, resources are mined, energy is used, and greenhouse gas emissions rise, threatening environmental sustainability. Further, rapid urbanization and trade liberalization in Pakistan have an influence on environmental sustainability that is both beneficial and harmful. Urbanization can result in higher resource use and pollution, but trade liberalization can promote industrialization and economic growth, which in turn raises energy use and emissions. It may, however, also support cleaner manufacturing techniques and assist the transfer of ecologically beneficial technology. Careful planning, legal frameworks, and investments in environmentally friendly infrastructure are all necessary for achieving this balance. Future development goals for Pakistan face a serious problem in achieving peaceful cohabitation. Based on above-mentioned facts this study explores the impact of Geopolitical Risk (GPR), Trade Liberalization (TR), and Resource Extraction (RE) on Pakistan's environmental sustainability. The study uses the Vector Error Correction (VEC) Model and Granger Causality Test to unravel the complex web of geopolitical complexities, trade dynamics, and energy consumption. Results show that non-renewable energy (i.e., 0.052), Resource Extraction (i.e., 0.028), Geopolitical Risk (i.e.,0.234), and industrialization (i.e., 0.070) negatively impact environmental sustainability, while Trade Liberalization (i.e., 0.040) and Urbanization (i.e., 0.437) promote positivity.

4.5. Policy recommendations

Based on research findings, following policies are recommended:

- ➢ Research shows that nonrenewable energy consumption negatively impacts the environment. Pakistan should prioritize measures to reduce nonrenewable energy consumption, such as offering financial incentives, adopting feed-in tariffs, and developing a clear plan for renewable energy capacity. Policymakers should also provide subsidies for renewable products to promote sustainable economic development. Turkey is an outstanding example of how to solve environmental issues while promoting sustainable growth, particularly because of its concentration on utilizing renewable energy sources. The development of frameworks for feed-in tariffs, investment incentive programs, and incentives for the growth of energy crops are just a few of the advanced renewable energy policies that the Turkish government has been at the forefront of. These initiatives reflect Turkey's admirable efforts to promote a cleaner and more sustainable future by jointly lowering greenhouse gas levels and carbon dioxide emissions.
- ➢ Pakistan should give diplomatic initiatives top priority if it wants to reduce regional tensions and improve relations with its neighbors. In this case we have best example of China. Through diplomatic channels, the creation of bilateral investment agreements, and the development of solid relationships, China has effectively sought stability. Geopolitical dangers have presented China with difficulties in its Belt and Road initiatives, but it has used international political dialogues and creative technology breakthroughs to improve environmental quality without increasing hazards. Countries like China may overcome obstacles and enhance environmental wellbeing by taking a diplomatic tack and using cutting-edge technical techniques.
- ➢ Pakistan should incorporate environmental clauses in trade agreements to capitalize on the positive impact of Trade Liberalization (TR) on environmental sustainability. To encourage ethical procurement, promote global environmental compliance, and ensure sustainable trade practices, Pakistan should include environmental provisions in trade agreements. These include encouraging eco-friendly packaging, obtaining raw materials with sustainability in mind, and making sure imported goods adhere to labor and environmental laws. Partnerships in trade, a reduction in carbon emissions, and adherence to international accords should all be contingent on adherence to global environmental norms.

4.6. Limitations of the study

- ➢ The research focuses on a small number of factors, including geopolitical risk, nonrenewable energy usage, trade liberalization, and environmental sustainability. Other relevant elements, both internal and external, may contribute to environmental sustainability but are not taken into account in the analysis.
- ➢ The backdrop of Pakistan was especially considered when conducting this study. But include South Asian economies in the study would give a more complete picture of the dynamics and trends in the area.
- ➢ The precision and correctness of the findings would probably be improved by extending the data timeline for this study. A more thorough and in-depth examination might be possible with a wider data set.

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Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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