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Sustainable development in Pakistan: explore the influence of institutions, industrialization, and tourism on consumption and territory-based emissions

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Abstract
In pursuing Sustainable Development Goals (SDGs), understanding the complex interplay between socioeconomic factors and carbon emissions is paramount. Given Pakistan's current environmental situation, this study scrutinizes the relationship between institutional quality, internal conflict, GDP, industrialization, foreign direct investment, external conflict, and international tourism influence on Pakistan's consumption-based and territory-based carbon emissions from 1990 to 2021 in the context of SDGs. Employing a robust analytical framework including ARDL, Single-Fourier-frequency, and Cumulative Fourier-frequency Granger Causality tests, findings reveal that improved institutional quality, industrialization, and foreign direct investment reduce consumption-based emissions. Meanwhile, institutional quality and foreign direct investment decrease territory-based emissions. Conversely, internal conflict and GDP growth intensify both consumption and territory-based emissions. The research contributes valuable insights for policymakers aiming to synchronize national growth with global sustainability goals, emphasizing the delicate balance needed to navigate economic and environmental complexities in achieving the SDGs.

Keywords Institutional quality · Internal · External conflicts · GDP · Industrialization · SDGs · ARDL

1 Introduction

The global landscape of economic development, environmental sustainability, and geopolitical dynamics is profoundly transformed, driven by an urgent collective commitment to the United Nations SDGs. The association between economic growth, environmental sustainability, and societal well-being is a critical field of research in emerging nations. Pakistan, being the world's fifth most populous country and a rising economy, provides a unique case study for comprehending these dynamics Worldometer, (2023). The pressing issue of climate change is worsened by the emission of carbon dioxide, which is further complicated by the intricacies of industry, internal disputes, and institutional quality

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Haldar and Sethi, (2021). Pakistan's carbon footprint is a multifaceted issue that necessitates a comprehensive analysis encompassing both consumption-based and territory-based metrics. This highlights the crucial need to examine the environmental effects of several factors, making the research novel in its approach.

In the literature, the relationship between economic activities and environmental degradation has been the subject of extensive debate. According to Grossman and Krueger, (1991), the Environmental Kuznets Curve (EKC) hypothesis posits that the environmental impact of an expanding economy rises until a specific income threshold is attained, at which point it begins to decrease. Nevertheless, there is a lack of research examining the potential of the EKC hypothesis in nations such as Pakistan, where institutional and regulatory structures are constantly changing. In an effort to fill this void, recent research has initiated investigations into the manner in which particular economic and political variables impact carbon emissions. For example, Mehmood et al., (2021) have identified the quality of institutions, which includes the efficacy of government policies and regulatory mechanisms, as a critical factor influencing environmental outcomes. Moreover, instability on the political front and internal strife can further compound environmental challenges by reallocating governmental focus and resources from safeguarding the environment to pressing security considerations Amin et al., (2021).

Economic factors, including foreign direct investment (FDI), industrialization, and GDP growth, have conventionally been regarded as catalysts for heightened carbon emissions on account of their dependence on energy-intensive operations. The significance of these factors, however, in the context of a developing nation where energy sources and industrial processes are frequently less efficient, merits closer inspection. As an illustration, a recent investigation conducted by Hussain, (2019) emphasized the deviation of industrialization in Pakistan from the customary EKC trajectory, predominantly attributable to antiquated technologies and lackadaisical environmental regulations. Likewise, an emerging area of interest is the impact of external conflicts on carbon emissions. The direction of economic resources and military spending have the potential to impact a nation's ability to regulate its environmental impact efficiently Warsame et al., (2023). Furthermore, regarding carbon emissions, international tourism, which is a substantial economic driver for Pakistan, exerts two distinct impacts. While it contributes significantly to the gross domestic product, it also increases carbon footprints due to the expansion of transport and hospitality services Bandyopadhyay et al., (2023). Although these considerations are important, the divergence between consumption-based and territory-based methods of estimating carbon emissions adds further intricacy. The first method calculates emissions based on consumption patterns, independent of the origin of commodities, whereas the later method focuses on emissions inside a country's boundaries. Precisely differentiating between global trade practices and local consumption is crucial for appropriately evaluating the environmental consequences Abbasi et al., (2021a, 2021b, 2021c).

Tourism has a direct and profound impact on the environment, affecting air, soil, water, and biodiversity. Indirectly, tourism activities also influence manufacturing, production, and transportation processes, contributing to environmental degradation. Solid waste generation and pollution associated with tourism further exacerbate environmental damage. Additionally, as tourism grows, there is often unchecked construction by local communities, leading to unplanned development and encroachment on natural habitats. These changes disrupt local ecosystems and have adverse effects on both the environment and human well-being Armughan, (2023). Though earlier research Abbasi, Abbas, et al., (2021); Abbasi et al., (2021a, 2021b, 2021c); Zheng et al., (2022) has indeed delved into the carbon emissions narrative from a territorial standpoint, a limited body of work simultaneously considers the consumption-based framework. Furthermore, existing literature scarcely navigates the relationships between carbon emissions, institutional quality, geopolitical conflicts, and economic growth. This study takes a pioneering step toward bridging these existing gaps by presenting a comprehensive analysis that not only examines consumption-based and territory-based emissions aligned with SDG 13 on climate action and SDG 9 on industry, innovation, and infrastructure.

The contribution of this research novel extends beyond the boundaries of academia, seeking to provide actionable insights that are not only informed by empirical firmness but are also eminently applicable to the country's policy formulation and strategic decision-making. First, this study significantly contributes by examining institutional quality (IQ), internal conflict (IC), GDP, industrialization (IND), foreign direct investment (FDI), external conflict (EC), and international tourism (IT) influence on consumption-based (CBCE) and territory-based carbon emissions (TBCE), in Pakistan from 1990 to 2021. Second, by harnessing the power of advanced analytical tools, including the ARDL model, and further bolstering the robustness of our findings, this study employs Single-Fourier-frequency Toda & Yamamoto Causality tests (SFTY) and Cumulative Fourier-frequency Granger Causality (CFTY) tests. It is worth underscoring that the methodology employed in this study, with its multi-faceted approach, uniquely positions us to capture the intricate nature of these relationships and to disentangle the multitude of influences at play. Third, our study contributes novel insights into the complex dynamics of conflicts and environmental degradation. While several studies have investigated the relationships between conflicts, institutional quality, and carbon emissions, none have focused explicitly on Pakistan. These examinations have consistently highlighted the disruptive influence of conflicts on environmental policies and have provided valuable insights into potential solutions. Against these backdrops, our study aims to fill this gap by focusing on both consumption-based and territory-based carbon emissions in Pakistan. By doing so, we aim to provide a comprehensive understanding of how conflicts interact with various socioeconomic factors to shape environmental outcomes in the country. Fourth, in the broader context, these findings offer more than just academic discourse; as it is present a tangible roadmap. By offering empirical evidence and insights, this study provides a compass for policymakers and stakeholders to steer the course towards a trajectory that resonates with SDG 13 on Climate Action, SDG 9 on Industry, Innovation, and Infrastructure, and the overarching ambition of the 2030 Agenda for SDGs. Finally, through this alignment with global sustainability imperatives, this research truly bridges the gap between academic exploration and real-world impact, illuminating a path that propels nations toward a more sustainable and prosperous future.

In the subsequent sections of this paper, we undertake an exploration of the critical dimensions that underpin our research. A comprehensive literature review contextualizes our study within the broader discourse of environmental sustainability, economic growth, and conflict dynamics. The methodology section delineates the precise tools and approaches employed to decipher the multifaceted relationships between variables. Results and their interpretations are presented in the subsequent segment, followed by a discussion of their implications and potential avenues for further research. Through this rigorous inquiry, we endeavor to contribute to the understanding of Pakistan's carbon footprint while enriching the broader discourse on sustainable development.

2 Literature review

The rapid economic development and globalization have sparked numerous debates about environmental consequences. This literature review aims to analyze Pakistan's carbon footprint utilizing both consumption-based and territory-based metrics. Table 9 (appendix) explain the acronyms used in this study.

2.1 GDP and industrialization: a double-edged sword

The consumption-based approach to carbon emissions acknowledges the intricate linkages between global trade, consumption patterns, and environmental impact. Consumption-based emissions encapsulate the carbon emissions produced in the manufacturing of goods and services that are later consumed in other countries. These components provide a comprehensive perspective on the direct and indirect drivers of carbon emissions. Earlier numerous studies Abbasi, Abbas, et al., (2021); Alam, (2018); Wang et al., (2018) explored the rapport between economic growth, industrialization, and carbon emissions. For instance, Talbi et al., (2022) stated Environmental Kuznets Curve (EKC) hypothesis posits an inverted U-shaped relationship between GDP and environmental degradation, suggesting that environmental impacts peak during industrialization but decline as countries transition to post-industrial economies. However, the applicability of the EKC to different countries and contexts remains a subject of debate. Khan et al., (2020) used second-generation panel cointegration to investigate G7 CO2 emissions' unexplained causes from 1990 to 2017. The long-term association between CO2 emissions, trade, income, environmental innovation, and renewable energy usage is confirmed. Abbasi et al., (2021a, 2021b, 2021c) investigated economic globalization, financial development, energy usage, GDP, and technical innovation on consumption and TBCE in Pakistan from 1990Q1 to 2019Q4. Employed dynamic ARDL and revealed GDP boosts consumption and TBCE in the short and long term. In Finland Kartal et al., (2022) used nonlinear and Fourier methods to study political stability, GDP, RE, and trade openness from 1990/Q1 through 2019/Q4. The empirical results show long-term cointegration between CBCE, political stability, and other factors. Positive shocks are more potent than negative shocks in trade openness, and GDP has a large effect on CBCE. In Denmark, Kirikkaleli et al., (2023) studied the effects of globalization on CBCE, GDP, patents, and the carbon intensity of GDP. New econometric techniques for analysis include nonlinear ARDL and Fourier ARDL, and dynamic OLS is used for robustness. The findings showed that CBCE, globalization, GDP, patents, and the carbon intensity of GDP had a substantial long-run association. Sun and Higham, (2021) stated that an extensive Tourist Carbon Information System (TCIS) consists of four crucial information parts: benchmarking, drivers and decarbonization progress, the carbon-economic nexus, and national tourist carbon footprint. The TCIS is then put to the test and used in New Zealand (2007–2013) to measure the carbon performance of the tourist industry and its rate of decarbonization in comparison to the country's average across all sectors. This important data defines the necessary mitigation trajectory for destinations to transition to a sustainable emissions route and illuminate future tourist development in relation to the national greenhouse gas assessment. Zhang et al., (2014) investigated using a multi-regional input–output model. The findings China's consumption-based CO2 emissions increased at an average annual growth rate of 8.8% from 3549 Mt in 2002 to 5403 Mt in 2007. Because of further urbanization and increased domestic demand, China's consumption-based emissions have much space to increase. Du et al., (2022) considered GDP and FDI as CCO2 emitters. It uses a 1990–2018 panel dataset and second-generation methods like CIPS and CADF unit root, Westerlund cointegration, FMOLS, DOLS, FE-OLS, and MMQR. The findings support the long-term relationship between CBCE and independent factors. The MMQR found that economic expansion, high-tech industry, and foreign direct investment raise CBCE in all quantiles, but renewable energy use decreases them. In the instance of Bolivia, Kirikkaleli and Oyebanji, (2022) assessed consumption-based carbon emissions that had been taken into account for global commerce. Bolivia has always maintained a negative trade deficit, according to research, which raises the possibility that consumption-based emissions in this region may increase in the current and beyond. Adebayo et al., (2022) investigated the impact of globalization and renewable energy utilization on CCO2, along with the function of nonrenewable energy usage and economic development in nations from 1990 to 2018. The cross-sectional dependence and heterogeneity tests found that slope heterogeneity and cross-sectional units differed among countries. Furthermore, the cointegration test results provided evidence of a long-run relationship between CBCE and the regressors. Furthermore, the results of both the CCEMG and the AMG revealed that economic growth and NRC contribute to environmental degradation, whereas globalization and renewable energy use help to mitigate environmental degradation. Meng et al., (2022) attempted a study to determine how trade diversification, green innovation, and the use of renewable energy sources affect carbon emissions in the BRICST nations from 1995 to 2020. The use of sophisticated panel data methods revealed empirical evidence of cointegration among the variables under investigation. The findings from the CS-ARDL model's long-term and short-term outcomes revealed an unfavorable association between trade diversification, green innovation, renewable energy, and carbon emissions.

2.2 Conflicts and institutional quality: unraveling complex dynamics

Internal and external conflicts are known to disrupt economies and social structures, impacting environmental policies and practices. Moreover, the quality of institutions and governance plays a crucial role in shaping environmental management strategies Obobisa et al., (2022). Studies exploring the connections between conflicts, institutional quality, and carbon emissions are necessary to comprehend the intricate relationships and their role in Pakistan's carbon footprint. Recently, Warsame et al., (2023) investigated the effects of internal and foreign conflicts, urbanization, and globalization on environmental deterioration in Somalia. With yearly time series data covering 1985 to 2016, the ARDL model, KRLS machine learning technique, and VECM approach are used. External conflict, globalization, and urbanization all promote environmental deterioration in the long run but not in the short run, with the exception of globalization, which has a positive effect on environmental quality in the short run. Internal strife, in particular, is insignificant in the short and long term. The study's findings are consistent across numerous analytical methodologies and environmental contamination indicators. Usman et al., (2021) studied the impact of internal and external conflicts on the ecological footprint of nations in the MENA from 1995 to 2016. They evaluate whether the EKC hypothesis is true for MENA nations during periods of internal and foreign conflict, which are marked by energy catastrophes and declining income levels. The findings reveal that income increase has a negative influence on ecological footprint, with evidence of intrinsic variation across quantile distributions. The positive influence of the square term of income, on the other hand, reduces ecological footprint, validating the U-shaped association between income and environmental index across MENA nations. Between 1984 and 2019, Qayyum et al., (2021) delved into how militarism and violent conflicts affected the degradation of the environment in South Asian nations. Cross-sectional dependence has been investigated using a second generational unit root test. The cointegration between a few chosen variables is examined using the Westerlund panel cointegration technique. Using the panel ARDL approach, long-run and short-run estimates have been computed. Additionally, the Granger Causality test is used, and the findings show a causative relationship between ecological footprint and armed conflict and militarization. Military spending, internal conflict, and foreign war all have a beneficial influence on ecological footprint, according to empirical estimations, and these findings are extremely significant in the short- and long-term.

Numerous theoretical propositions have highlighted the crucial role of globalization and technological advancement in promoting environmental sustainability. A study conducted by Ahad and Khan, (2016) employed the ARDL method to investigate the interplay between globalization, GDP, environmental utilization, and environmental protection in Bangladesh spanning from 1972 to 2015. The study revealed a positive correlation between these factors. The outcomes underscored a favorable relationship connecting globalization, the EU, industrial activities, and the degradation of the environment. Additionally, it was observed that ED could contribute positively to long-term environmental performance. Another examination, carried out by Kwabena Twerefou et al., (2017), scrutinized the nexus between globalization, ED, environmental safeguarding, and sustainability in Sub-Saharan Africa, focusing on the years 1990–2013. The findings lent support to the validity of the Environmental Kuznets Curve in the region, highlighting that globalization tends to exacerbate environmental harm and exert detrimental effects on sustainability. In contrast, the study found that ED could have advantageous impacts on climate change mitigation and sustainability within the same region. Asongu et al., (2019) delved into the influence of globalization on environmental excellence and governance in Sub-Saharan Africa during the period 2000–2012. The analysis using GMM revealed that the mechanisms underlying trade liberalization and climate change, as gauged by CO2 emissions, yield positive outcomes on various development indicators. However, the study noted that statistics from FDI might not be as reliable as those from domestic sources.

The prevailing consensus among researchers is that green innovation can play a beneficial role in curbing carbon emissions and improving environmental well-being. Recent exploration of transnational data by Fei et al., (2014) investigated the link between TI and CO2 emissions in Norway and New Zealand over the period 1971–2010, utilizing an ARDL model. Their findings indicated that investments in R&D could facilitate the adoption of cleaner energy sources. Several studies have probed the relationship between TI, GDP, and other variables in relation to carbon emissions Chen et al., (2021); Fang et al., (2019); Gozgor et al., (2019); Iqbal et al., (2021). Some researchers also adopted a PCO2 metric to assess environmental degradation. Recently, there has been a shift towards using CCO2 as a measure of environmental deterioration. However, limited research has focused on the determinants of CCO2 emissions, with only a handful of studies, including those by Khan et al., (2020); Safi et al., (2021), exploring this aspect using diverse methodologies and connecting various variables. Another study by Hasanov et al., (2018) explored the impact of international trade on CO2 emissions in nine oil-exporting countries from 1995 to 2013, employing a panel cointegration method. The study did not find a substantial effect on TBCE; however, it identified a significant impact on CBCE in both the short and long terms, with the directions of these effects differing.

The above literature review shows that Country-Specific studies in various countries are analyzed individually. For instance, research conducted in Finland, Denmark, China, and Bolivia examines the relationships between carbon emissions, political stability, economic expansion, FDI, and trade openness. Also tourism and carbon footprint, a significant study introduces the Tourist Carbon Information System (TCIS) and applies it to New Zealand's tourism industry Fei et al., (2014). This system evaluates the carbon performance of tourism and offers insights into mitigation strategies for sustainable tourism development. Moreover, internal and external conflicts and institutional quality impact on environmental degradation are explored. The role of institutional quality and governance in shaping environmental management strategies is emphasized only in Somalia, MENA and South Asian nations.

3 Methodology

3.1 Data collection

The primary source of data for this study is the various extensive database, which provides comprehensive and reliable information on various economic, environmental, and conflict-related indicators. The data covers a multi-year span of 1990–2021 to capture long-term trends and fluctuations in the selected variables. Table 1 provides a detailed description of the determinants being examined in the study.

Additionally, for more appropriate data visualization, a heat map technique is used to represent the magnitude of a phenomenon as color in a two-dimensional space. It is a graphical representation where values in a matrix are depicted as colors, allowing easy visualization of complex data patterns or distributions. Figures 1, 2, 3, 4, 5, 6, 7 for model 1 represent the heat maps, where CBE signifies consumption-based emissions, as explained by factors. In contrast, Institutional Quality (IQ), Internal Conflict (IC), Gross Domestic Product (GDP), Industrialization (IND), Foreign Direct Investment (FDI), External Conflict (EC), and International Tourism (IT) are explanatory. Each figure is commonly signified as grids, with rows and columns corresponding to different categories, variables, or periods. Each cell in the grid represents a value. The intensity or color of each cell is determined by the value it represents. Typically, a color scale is used where colors range from one end of the spectrum to another (e.g., red or blue) to represent low to high values and (e.g., pink or sky blue) moderate effects, respectively. For instance, shades of red indicate higher values, while shades of blue indicate lower values.

Figures 8, 9, 10, 11, 12, 13, 14 in Model 2 showcase heat maps that depict Territory-Based Emissions (TBE) as the focal point, influenced by various factors. These factors encompass Institutional Quality (IQ), Internal Conflict (IC), Gross Domestic Product (GDP), Industrialization (IND), Foreign Direct Investment (FDI), External Conflict (EC), and International Tourism (IT). Each heat map comprises a grid structure, where rows and columns correspond to distinct categories, variables, or chronological periods. Within this grid, individual cells represent specific values.

The color gradient employed within these heat maps serves as a visual indicator of magnitude. Typically, a color spectrum ranging from, for instance, blue to yellow signifies low to high values, with intermediate values represented by shades of green and light blue, indicating moderate to low values, respectively. For instance, warmer shades, such

Table 1 Determinants examined in study

Variable	Description	Unit	Data Sources
CBCE	consumption-based carbon emissions	Metric tonnes of CO2	Global carbon atlas (GCA) database
TBCE	Territory or production-based emissions		Friedlingstein et al., (2020)
GDP	economic growth	(constant LCU)	WDI, (2021)
IQ	Institutional Quality	Ranked (0 – 100)	
FDI	Foreign direct investment, net inflows	(BoP, current US$),	
Industrialization	Industry (including construction), value-added	(% of GDP)	
Tourism	International tourism, expenditures for travel items	(current US$)	
Internal conflict	A sum of risk rating is assigned to three subcomponents	civil war/coup threat, terrorism/political violence, and civil disorder	International Country Risk Guide (ICRG) PRS Group (https://www.countryrisk.io)
External conflict		War, cross-border conflict, and foreign pressure	

Fig. 1 IQ and CBE

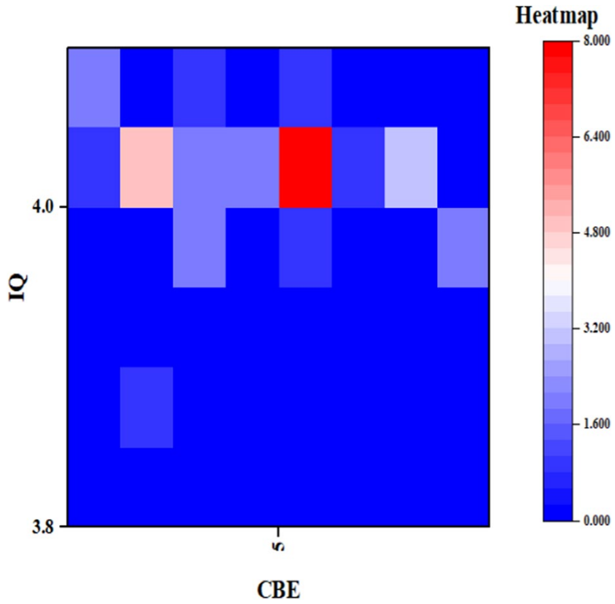
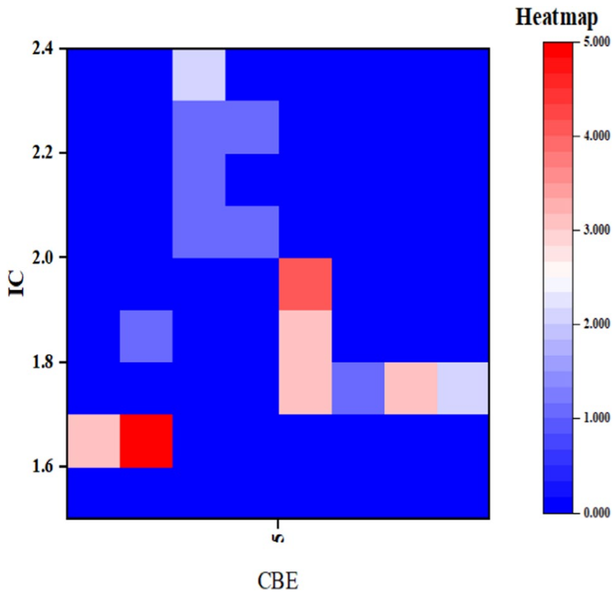


Fig. 2 IC and CBE



as green, suggest higher values, while more fabulous shades, such as blue, signify lower values.

These visual representations offer a means to interpret and analyze the relationships and patterns between TBE and the associated influencing factors. They serve as practical tools for comprehending complex data sets highlighting trends, correlations, or discrepancies within the studied variables.

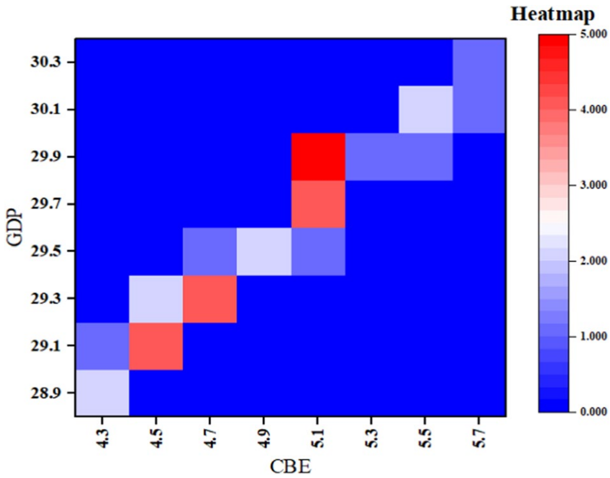


Fig. 3 GDP and CBE

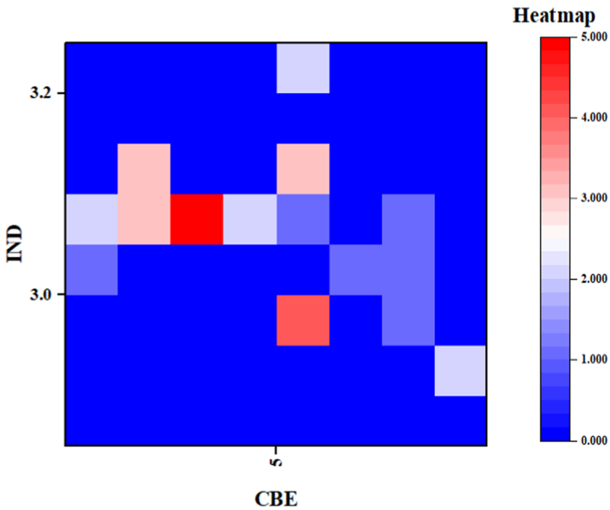


Fig. 4 IND and CBE

3.2 Variables selections

3.2.1 Dependent variables

The study analyzes two main dependent variables: consumption-based carbon emissions (CBCE) and territory-based carbon emissions (TBCE). These metrics provide insights into the environmental impact of economic activities, both domestically and in terms of global trade.

Fig. 5 FDI and CBE

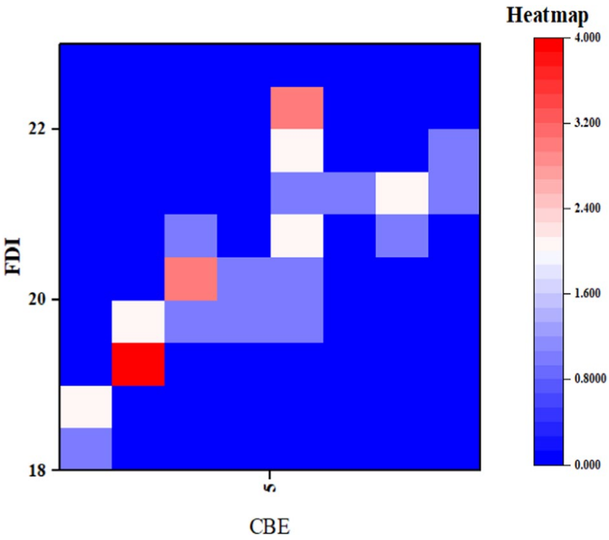
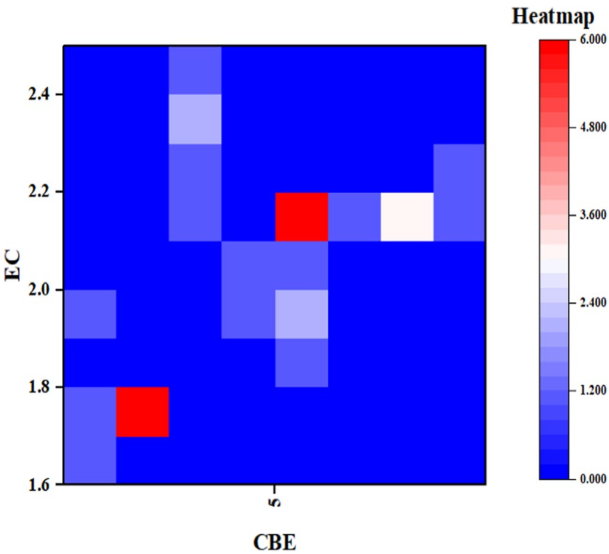


Fig. 6 EC and CBE



3.2.2 Independent variables

The independent factors under consideration encompass a range of dimensions: Institutional Quality: Institutional quality indices are included to assess the role of governance and policies in shaping carbon emissions $\alpha_i^1 = \frac{\partial CBCEandTBCE_{it}}{\partial IQ_{it}} < 0$. Conflicts: The presence of internal and external conflicts is investigated to ascertain their impact on carbon emissions, reflecting disruptions in governance and infrastructure which might be unfavorable $\alpha_i^{2,3} = \frac{\partial CBCEandTBCE_{it}}{\partial ICandEC_{it}} > 0$. GDP: The study examines GDP, represented income levels, to understand their association with carbon emissions $\alpha_i^4 = \frac{\partial CBCEandTBCE_{it}}{\partial GDP_{it}} > 0$. Industrializa-

Fig. 7 IT and CBE

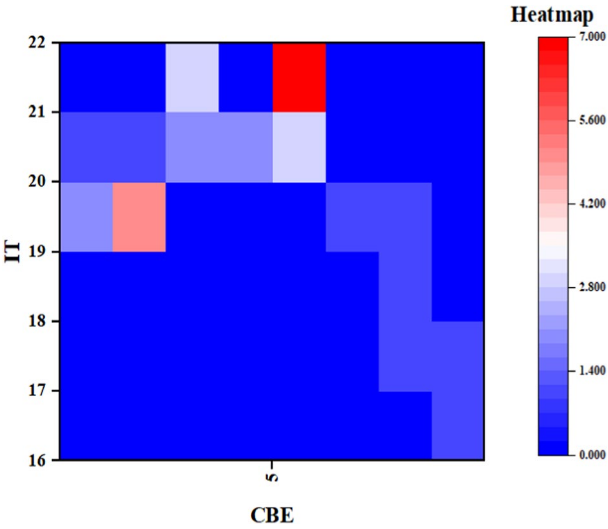
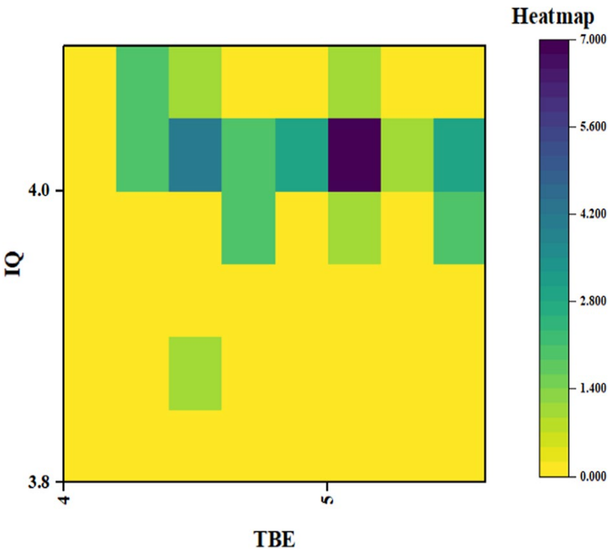


Fig. 8 IQ and TBE



tion Indicators: This variable represents the contribution of the industrial sector, including construction activities, to the country's GDP. It serves as a proxy for the level of industrialization to explore their potential contributions to carbon emissions expected to rise $\alpha_i^5 = \frac{\partial \text{CBCE and TBCE}_{it}}{\partial \text{IND}_{it}} > 0$. Foreign Direct Investment (FDI): The study explores the relationship between FDI and carbon emissions, assessing whether foreign investments influence environmental outcomes $\alpha_i^6 = \frac{\partial CBCEandTBCE_{it}}{\partial FDI_{it}} \langle 0 \rangle$. The rapid growth of international tourism (IT) in Pakistan presents both opportunities and challenges for sustainable development. While tourism contributes to economic growth, job creation, and cultural exchange, it also poses environmental risks, particularly in terms of carbon emissions and resource depletion. Hence, the relationship between IT expenditures for travel items and

Fig. 9 IC and TBE

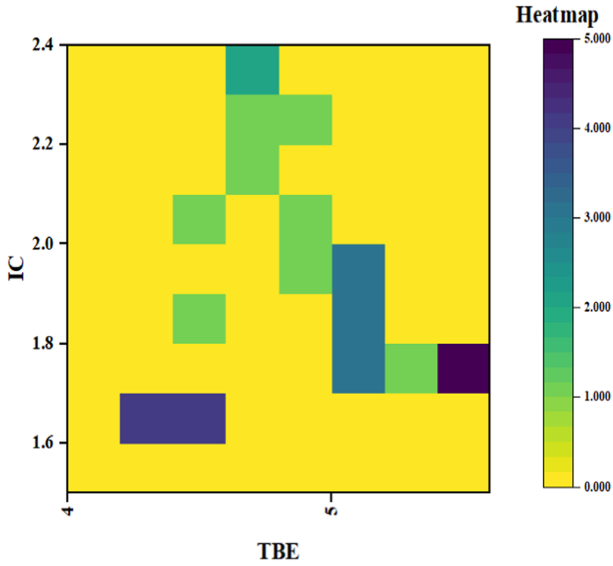
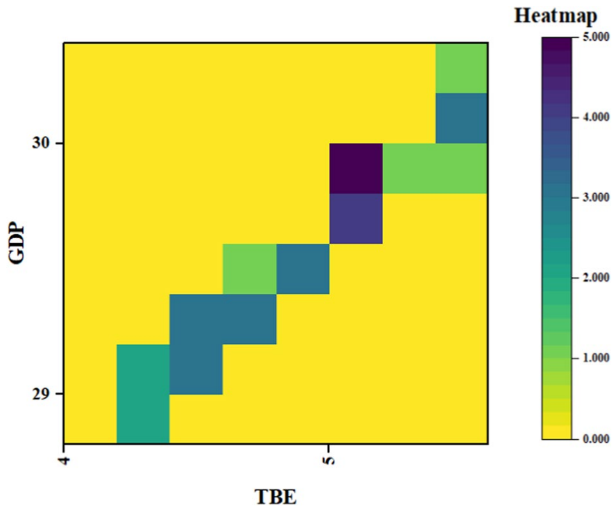


Fig. 10 GDP and TBE



consumption-based carbon emissions in Pakistan is multifaceted and influenced by various interconnected factors. The impact of international tourism on carbon emissions is not only driven by direct travel-related activities but also by the broader economic, social, and environmental dynamics associated with tourism $\alpha_i^7 = \frac{\partial \text{CBCE and TBCE}_{it}}{\partial \text{IT}_{it}} > 0$.

3.3 Research design

This study employs a quantitative research design to analyze the relationships between consumption-based and territory-based carbon emissions metrics as dependent variables. The study investigates various independent factors, including IQ, IC, GDP, IND,

Fig. 11 IND and TBE

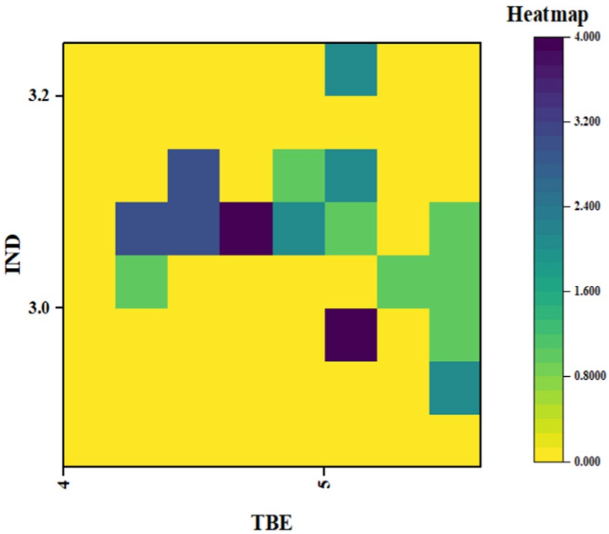
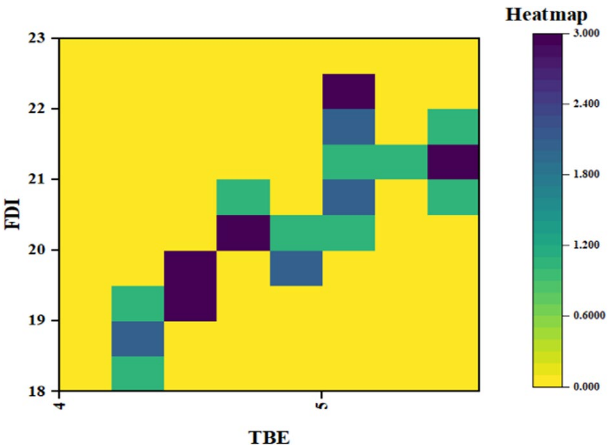


Fig. 12 FDI and TBE



FDI, EC and IT. The following analytical techniques are employed to test the hypotheses and examine the relationships. The ARDL model is applied to analyze the short and long-run relationships between the dependent and independent variables. Also, in this study, the innovative cumulative Fourier frequency causality test, as outlined in Nazlioglu et al., (2016), (2019), was adopted. This approach, alternatively referred to as the "gradual shift causality test" or "Fourier Toda-Yamamoto causality test," allows for seamless and gradual shifts during causality analysis. Importantly, this method eliminates the need for prior knowledge of structural breaks. Subsequently, the Toda and Yamamoto, (1995) method was introduced, addressing the limitations related to cointegration and the robustness against unit root assumptions presented by Granger, (1969). Nevertheless, the Toda and Yamamoto, (1995) approach is susceptible to changes in causality estimates due to structural shifts. The triangulation of econometric techniques, robustness tests, and various independent factors enhance the validity and reliability of

Fig. 13 EC and TBE

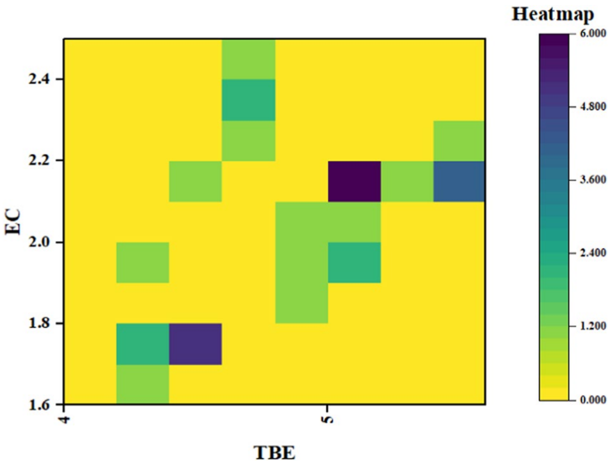
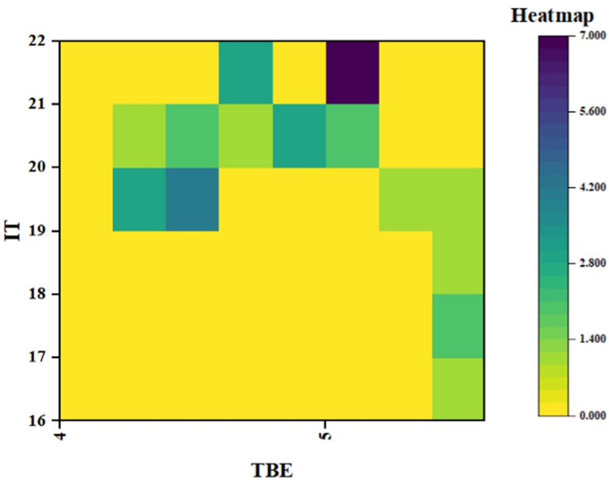


Fig. 14 IT and TBE



the study's outcomes, contributing to a comprehensive understanding of the complex interactions between the variables. The preceding dialogue guides us towards formulating an empirical model within the current framework, following Bandyopadhyay and Rej, (2021) subsequently incorporating variables:

Model: 1

$$CBCE_t = \mathrm{f}\left(IQ_t, IC_t GDP_t, IND_t FDI_t, EC_{t,} IT_t\right) \tag{1}$$

Model: 2

$$TBCE_t = \mathrm{f}\left(IQ_t, IC_t GDP_t, IND_t FDI_t, EC_{t,} IT_t\right) \tag{2}$$

The previously presented framework has been refined into a log-linear structure, a choice made to enhance the precision and stability of predictions when contrasted with a linear model. This log-linear construction offers a more compelling and effective approach for modeling the relationship Bandyopadhyay et al., (2023). Therefore, the model is rebuilt in the following manner:

Model: 1

$$lnCBCE_t = \alpha_0 + \alpha_1 lnIQ_t + \alpha_2 lnIC_t + \alpha_3 lnGDP_t + \alpha_4 lnIND_t + \alpha_5 lnFDI_t + \alpha_6 lnEC_t + \alpha_7 lnIT_t + \varepsilon_t \quad (3)$$

Model: 2

$$lnTBCE_t = \alpha_0 + \alpha_1 lnIQ_t + \alpha_2 lnIC_t + \alpha_3 lnGDP_t + \alpha_4 lnIND_t + \alpha_5 lnFDI_t + \alpha_6 lnEC_t + \alpha_7 lnIT_t + \varepsilon_t \quad (4)$$

where $CBCE_t$ represents consumption-based emissions,$TBCE_t$ territory-based emissions as explained factors, IQ_t denotes institutional quality, IC_t Internal Conflict, GDP_t gross domestic products, IND_t industrialization, FDI_t foreign direct investment, EC_t external conflict, IT_t international tourism and ε_t is the random error term.

3.4 Cointegration approach

The Autoregressive Distributed Lag (ARDL) method is a modelling technique utilized to examine the short-term dynamics of variables in addition to their long-run relationship. The ARDL model is highly advantageous when applied to time series data analysis, such as in econometrics, to examine the dynamic interactions that occur between variables as time passes Bölük and Mert, (2015). Within the ARDL framework, the term "short term" generally denotes the transient or instantaneous impacts that modifications in the independent variables impose on the dependent variable. The model incorporates the coefficients of the lagged independent variables to capture these short-term effects. They illustrate the manner in which the dependent variable reacts to alterations in the independent variables during the present and preceding periods Abbasi et al., (2025).

Conversely, "long term" pertains to the enduring or cumulative impacts that modifications in the independent variables have on the dependent variable throughout an extended period. The coefficients of the levels of the independent variables in the model capture these long-term effects. These values symbolize the steady-state or equilibrium relationship among the variables subsequent to the completion of all short-term adjustments. The ARDL bound test introduced by Pesaran et al., (2001) enables scientists to ascertain the presence of a long-run relationship between variables and, if so, the sequence in which the variables integrate. The F-statistic and critical values obtained through simulation methodologies form the foundation of this assessment. The ARDL approach enables researchers to examine long-term equilibrium relationships as well as short-term dynamics within a singular framework, thereby facilitating a comprehensive comprehension of the interconnections among the variables being investigated. To attain robust parameter estimates, the following equation is adhered to:

Model: 1

$$\Delta CBCE_t = \beta_0 + \beta_1 CBCE_{t-1} + \beta_2 IQ_{t-1} + \beta_3 IC_{t-1} + \beta_4 GDP_{t-1} + \beta_5 IND_{t-1} + \beta_6 FDI_{t-1} + \beta_7 EC_{t-1} + \beta_8 IT_{t-1} \sum_{j=1}^{k_1} \lambda_{1j} \Delta CBCE_{t-j} + \sum_{j=0}^{k_2} \lambda_{2j} \Delta IQ_{t-j} + \sum_{j=0}^{k_3} \lambda_{3j} \Delta IC_{t-j} + \sum_{j=0}^{k_4} \lambda_{4j} \Delta GDP_{t-j} + \sum_{j=0}^{k_5} \lambda_{5j} \Delta IND_{t-j} + \sum_{j=0}^{k_6} \lambda_{6j} \Delta FDI_{t-j} + \sum_{j=0}^{k_7} \lambda_{7j} \Delta EC_{t-j} + \sum_{j=0}^{k_8} \lambda_{8j} \Delta IT_{t-j} + \Delta_{1t} \tag{5}$$

Model: 2

$$\Delta TBCE_t = \beta_0 + \beta_1 TBCE_{t-1} + \beta_2 IQ_{t-1} + \beta_3 IC_{t-1} + \beta_4 GDP_{t-1} + \beta_5 IND_{t-1} + \beta_6 FDI_{t-1} + \beta_7 EC_{t-1} + \beta_8 IT_{t-1} \sum_{j=1}^{k_1} \lambda_{1j} \Delta TBCE_{t-j} + \sum_{j=0}^{k_2} \lambda_{2j} \Delta IQ_{t-j} + \sum_{j=0}^{k_3} \lambda_{3j} \Delta IC_{t-j} + \sum_{j=0}^{k_4} \lambda_{4j} \Delta GDP_{t-j} + \sum_{j=0}^{k_5} \lambda_{5j} \Delta IND_{t-j} + \sum_{j=0}^{k_6} \lambda_{6j} \Delta FDI_{t-j} + \sum_{j=0}^{k_7} \lambda_{7j} \Delta EC_{t-j} + \sum_{j=0}^{k_8} \lambda_{8j} \Delta IT_{t-j} + \Delta_{1t} \tag{6}$$

Here, Δ, is the difference operator, with β0 representing the constant term, β1 standing for the coefficient of the trend component, and β1 through β6 representing the long-run coefficients. Additionally, λ_{1j} to λ_{8j} signify the short-run coefficients, t − 1 corresponds to the number of optimal lags, and ε_{it} signifies the error term.

3.5 Novel causality approach

The approach developed by Toda and Yamamoto, (1995) is rooted in the vector autoregressive (VAR) framework initially formulated by Sims, (1980). In the process of determining the optimal lag length, $\rho + d_{max}$ is introduced alongside the lag of d_{max}, which signifies the highest integrated order within the time series. Consequently, this modification yields inaccurate results within the VAR model itself, as noted by Enders and Jones, (2016); Enders and Lee, (2012).

To address these limitations, Nazlioglu et al., (2016) extended the Fourier-based Toda-Yamamoto causality test into five distinct models. These models were devised to account for structural shifts in the Granger causality assessment and incorporate gradual shifts smoothly. This variant is also referred to as the "gradual shift causality examination." Additionally, the Fourier Granger causality test was introduced, which utilizes both a single frequency (SF) approach and cumulative frequencies (CF) approach. This technique, known as the Fourier method, was introduced by Nazlioglu et al., (2019). A more contemporary innovation, the modernized Wald test statistic (MWALT), emerged by combining TY-VAR analysis with Fourier approximation. The CFTY test evaluates causal connections for Model–1 and Model–2. Given the constancy of intercept coefficients over periods, the VAR model's evolution is described as follows:

$$y_t = \sigma_0 + \gamma_1 \sin\left(\frac{2_{\pi kt}}{T}\right) + \gamma_2 cos\left(\frac{2_{\pi kt}}{T}\right) + \beta_1 y_{t-1} + \ldots + \beta_{\rho+d} y_{t-(\rho+d)} + \varepsilon_t \tag{7}$$

In this scenario, the examination centers around testing the H0 of the absence of causality (H0: ß1 = ß0 = 0), and the validation of this hypothesis will rely on the application of the Wald statistic. Concurrently, this study conducts diagnostic assessments to evaluate the model stability of CUSUM and CUSUM SQUARE. To this end, the Breusch Godfrey Lagrange multiplier (LM) is employed. The evaluation of heteroscedasticity is facilitated by the implementation of the Breusch Pagan Godfrey (BG) test. Furthermore, for testing model specification, the Ramsey reset test is applied.

4 Results and discussion

The descriptive statistics in Table 2 table reveal several critical insights about the variables examined. Notably, the mean values of CBCE and TBCE are close, implying a balanced distribution. The IQ variable exhibits negative skewness, suggesting a left-leaning distribution of data, while the IND variable's high kurtosis indicates a peaked distribution. Moreover, the GDP values have a relatively low standard deviation, indicating stability in economic growth. The FDI variable shows notable variability with a more significant standard deviation. Interestingly, the IC variable's Jarque–Bera test statistic and probability indicate a significant departure from normality. In essence, the statistics shed light on the distribution, variability, and normality characteristics of the examined variables. These findings contribute to a comprehensive understanding of the dataset's key features, supporting informed decision-making and further analysis. Appendix Fig. 17 depicts the correlation matrix, showing CBCE and TBCE with strong positive correlations with GDP and moderate positive correlations with FDI and EC, while also displaying weak negative correlations with IQ and IT, suggesting nuanced relationships. Additionally, IC exhibits weak positive correlations with GDP and EC, implying improvements in GDP and EC with better IC.

The stationarity of each variable shown in Table 3 was evaluated using ADF, PP, and KPSS tests. The outcomes infer that the examined series does not exhibit stationarity at the second difference or possess an integrated order of I(2). However, ADF and PP results show that IQ is statistical significance at the level. At the first point of divergence, all series exhibit statistical significance. The results of the KPSS test suggest that, with the exception of IQ, IC, and IT, all other variables exhibit statistical significance at the I(0) level. Only IT demonstrates statistical significance at the first difference or I(1) level. The comprehensive

Table 2 Descriptive statistics

Statistics	CBCE	TBCE	IQ	IC	GDP	IND	FDI	EC	IT
Mean	4.94	4.88	4.01	1.85	29.55	3.06	20.39	2.04	20.13
Median	5.02	4.94	4.03	1.79	29.51	3.08	20.39	2.11	20.61
Maximum	5.71	5.53	4.06	2.37	30.20	3.24	22.44	2.41	21.51
Minimum	4.25	4.21	3.85	1.61	28.88	2.90	18.48	1.67	16.54
Std. Dev	0.41	0.40	0.04	0.23	0.38	0.07	1.10	0.20	1.26
Skewness	0.14	0.07	−2.24	0.85	−0.01	0.21	0.13	−0.22	−1.23
Kurtosis	2.15	2.08	10.35	2.71	1.86	3.73	2.15	1.93	3.91
JB	1.07	1.16	98.92	3.95	1.73	0.95	1.05	1.78	9.17
Probability	0.59	0.56	0.00	0.14	0.42	0.62	0.59	0.41	0.01

Table 3 Unit root inspection

Variables	With Constant I(0)			With Constant I(1)		
	ADF	PP	KPSS	ADF	PP	KPSS
CBCE	−0.19	0.35	0.74***	−4.63***	−4.64***	0.11
TBCE	−0.99	−0.37	0.74***	−3.60*	−3.66***	0.06
IQ	−5.72***	−5.72***	0.12	−5.70***	−26.27***	0.31
IC	−2.03	−1.67	0.15	−3.58**	−3.57**	0.18
GDP	0.56	−0.42	0.76***	−4.39***	−3.67**	0.09
IND	−2.41	−2.28	0.37*	−6.74***	−6.61***	0.26
FDI	−1.32	−1.41	0.62**	−4.44***	−4.50***	0.06
EC	− −2.61	−1.68	0.41*	−5.09***	−5.09***	0.05
IT	0.35	0.14	0.20	−3.93**	−4.16***	0.38*

***, **, * implies 1%, 5% and 10%

results indicated the absence of any patterns at level I(2). This interaction confirms that the ARDL model may be extended to include both I(0) and I(1) orders.

The ARDL bound test serves the purpose of assessing the enduring relationship between study variables. Presented in Table 4 are the outcomes of this test, revealing whether a stable, long-term connection exists. The evaluation is undertaken for two distinct models, designated as "Model–1" and "Model–2." At the crux of this examination lie the F-statistic and t-statistic values, pivotal measures used to gauge the significance of coefficients within a regression model. Crucially, the ARDL bound test hinges on whether these computed statistics surpass a predetermined threshold known as the "upper bound," derived from statistical distributions. The inference drawn from the presented information is that both "Model–1" and "Model–2" exhibit a sustained long-term relationship among the study variables. This inference stems from the observation that the calculated F- and t-statistic values exceed the established upper bound, thus affirming statistical significance and substantiating the presence of a cointegrating relationship.

Table 4 The analysis of ARDL bounds test

CBCE = f (IQ, IC, GDP, IND, FDI, EC, IT)				Model–1 (critical values)		
Significance	Value	K	10%	5%	1%	Level
F-statistics	8.32***	7	2.03	2.32	2.96	I(0)
			3.13	3.5	4.26	I(1)
T- statistics	−5.10***		−2.57	−2.86	−3.43	I(0)
			−4.23	−4.57	−5.19	I(1)
TBCE = f (IQ, IC, GDP, IND, FDI, EC, IT)				Model–2 (critical values)		
F-statistics	5.82***		2.03	2.32	2.96	I(0)
			3.13	3.5	4.26	I(1)
T- statistics	−4.89***		−2.57	−2.86	−3.43	I(0)
			−4.23	−4.57	−5.19	I(1)

*** substantial at the 1%

4.1 Consumption-based carbon emissions outcome (Model-1)

The short and long-term coefficient estimates were obtained from the ARDL estimations, as shown in Table 5 (Model-1). In the short run, the coefficient estimate between institutional quality (IQ) and consumption-based carbon emissions (CBCE) suggests that a change in IQ has an immediate impact on CBCE. Specifically, for each 1% increase in IQ, CBCE is projected to decrease by 0.90%. This implies that improvements in institutional quality have an immediate dampening effect on CBCE in Pakistan.

In the long run, the coefficient estimates between IQ and CBCE indicate the sustained impact of IQ on CBCE over an extended period. Here, a 1% increase in IQ is associated with a greater reduction in CBCE, specifically by 1.22%. This suggests that over time, improvements in institutional quality continue to exert a more significant influence on decreasing CBCE in Pakistan. Overall, the ARDL estimations from Model 1 reveal that institutional quality has both short- and long-term effects on consumption-based carbon emissions in Pakistan. The negative coefficients (− 0.90 in the short run and − 1.22 in the long run) highlight the inverse relationship between IQ improvements and CBCE, implying that enhancing institutional quality can contribute to a reduction in carbon emissions, both immediately and over the long haul. The findings are consistent with Azam et al., (2021)b, (2021)a; Meo et al., (2021) demonstrated the influence of IQ on CO2 emissions.

Internal conflict impacts consumption-based carbon emissions in Pakistan both in the short and long term. A 1% increase in internal conflict results in a 0.13% immediate rise in emissions, reflecting its swift influence. Over the long run, this effect becomes more pronounced, with the same increase in conflict leading to a 0.17% increase in emissions.

Table 5 Short and long-run ARDL estimation

Determinants	Model—1			Model—2		
	Coeff	Std. error	t-value	Coeff	Std. error	t-value
Short-run						
Cons	− 21.32	4.92	− 4.34***	− 23.66	5.29	− 4.47***
ΔIQ_{t-1}	− 0.90	0.39	− 2.31**	− 0.92	0.30	3.07**
ΔIC_{t-1}	0.13	0.06	1.94*	0.14	0.07	1.94*
ΔGDP_{t-1}	1.15	0.19	6.03***	1.18	0.22	5.40***
ΔIND_{t-1}	− 0.23	0.12	− 2.00*	− 0.35	0.22	− 1.59
ΔFDI_{t-1}	− 0.16	0.03	− 6.34***	− 0.14	0.03	− 4.61***
ΔEC_{t-1}	− 0.10	0.07	0.20	− 0.10	0.09	− 1.13
ΔIT_{t-1}	0.01	0.01	1.42	0.02	0.01	1.60
Long-run						
IQ_t	− 1.22	0.58	− 2.09*	− 1.12	0.41	− 2.74**
IC_t	0.17	0.08	2.27**	0.17	0.07	2.31**
GDP_t	1.57	0.09	17.05***	1.43	0.08	16.91***
IND_t	− 1.08	0.35	− 3.13**	− 0.42	0.285	− 1.481
FDI_t	− 0.22	0.04	− 5.55***	− 0.17	0.038	− 4.308***
EC_t	− 0.14	0.10	− 1.37	− 0.123	0.106	− 1.162
IT_t	0.02	0.02	1.25	0.022	0.016	1.377

***, **, * means the 10%, 5%; and 1% significant level

This suggests that internal conflict consistently contributes to higher carbon emissions over extended periods. The outcomes are consistent with Qayyum et al., (2021) stated that internal and external conflict have a positive impact on ecological footprint. In contrast, Warsame et al., (2023) reported no effect on the environment.

The findings regarding the relationship between GDP and consumption-based carbon emissions in Pakistan carry significant implications. The observed dual effects underscore the intricate dynamics at play. In the short term, as GDP grows by 1%, there is an immediate 1.15% surge in emissions. This highlights the immediate environmental consequences associated with economic growth. Moreover, the long-term perspective unveils a more substantial impact. A 1% GDP increase corresponds to a 1.57% emissions rise over an extended period. This underscores the compounding effect of economic growth on carbon emissions. Such insights emphasize the need for a comprehensive approach to sustainability, recognizing the interplay between economic prosperity and environmental stewardship. The outcomes are comparable to Abbasi et al., (2025); Kirikkaleli et al., (2023).

The short- and long-term coefficients of industrialization (IND) reveal a consistent impact on consumption-based carbon emissions (CBCE) in Pakistan. Specifically, a 1% increase in industrialization leads to a decrease of 0.23% in CBCE in the short run and a more substantial 1.08% decrease in the long run. These results underline the significant role of industrialization in shaping carbon emissions trends. In the short term, industrialization exhibits a relatively modest influence on emission reduction, while its long-term impact becomes more pronounced. This highlights the importance of balancing industrial growth with emission reduction strategies to ensure an eco-friendlier trajectory for Pakistan's development. Our findings endorse the recent study by Mehmood et al., (2023) specified an adverse association between industry and emissions in Pakistan. While contrary to Abbasi et al., (2021a, 2021b, 2021c) indicated that IND boosts the environmental sustainability of the UK.

Further, foreign direct investment (FDI) in the short term, divulge a negative bond between FDI on CBCE, with a 1% increase in FDI resulting in a 0.16% reduction in CBCE. In the long term, this relationship becomes more pronounced, as a 1% increase in FDI leads to a more considerable reduction of 0.22% in CBCE. The aforementioned data highlight the significance of FDI in influencing the dynamics of carbon emissions. In the short term, FDI demonstrates a modest level of effect on the reduction of emissions; however, its impact grows much higher in the long run. This underscores the capacity of foreign investment to make significant contributions towards achieving sustainable environmental results over prolonged periods. In the context of Pakistan, the findings above emphasize the significance of obtaining FDI as a means to promote both economic growth and environmental stewardship. The outcome confirms that Wang et al., (2022) disclosed the adverse impact of FDI on carbon emissions. Conversely, Haug and Ucal, (2019) found no significant effects of FDI. External conflict and international tourism outcomes show no significant impact on consumption-based carbon emissions in Pakistan. This suggests that changes in these variables do not have statistically significant effects on emissions.

4.2 Territory-based carbon emissions outcome (Model-2)

Analyzing the territory-based carbon emissions (TBCE) outcomes within Model 2 highlights the role of institutional quality (IQ), internal conflict (IC), GDP, industrialization (IND), foreign direct investment (FDI), external conflict (EC) and international tourism (IT) in Pakistan's emissions trends.

Among these, IQ emerges as a significant influencer of TBCE, demonstrating both short and long-term impacts. In Pakistan, IQ is a pivotal factor influencing TBCE. A 1% increase in IQ leads to a 0.92% reduction in TBCE in the short, reflecting swift governance-driven emissions control. Over the long term, this impact amplifies, resulting in a substantial 1.12% decrease in TBCE. Improved institutional quality signifies robust governance, efficient regulations, and effective policy implementation. Over time, elevated institutional quality supports long-lasting emissions reduction through consistent enforcement of standards, fostering a greener trajectory for Pakistan's development. The outcomes corroborate Ahmed and Le, (2021); Azam et al., (2021)b discovered that institutional quality has a significant impact on the environment.

Conversely, the impact of internal conflict on territory-based carbon emissions (TBCE) is noteworthy. A 1% increase in internal conflict leads to adverse effects, causing a 0.14% rise in TBCE in the short term and a larger 0.17% increase in the long term. These findings underscore the urgency of addressing internal conflict for environmental mitigation. Effective conflict resolution becomes paramount to limit conflict-driven emissions. Achieving stability and harmony within the region emerges as a key strategy for curbing territory-based carbon emissions, aligning environmental protection with social well-being. GDP impact on territory-based carbon emissions (TBCE) is intricate. GDP growth corresponds to a short-term 1.18% increase and a long-term 1.43% increase in TBCE. This underscores the complex connection between economic expansion and emissions. Short-term gains are coupled with immediate emissions challenges, while long-term effects intensify, highlighting the significance of aligning economic growth with emissions reduction strategies for sustainable development. The findings are in line with Ahmed et al., (2021); Yi et al., (2023).

Industrialization's impact on territory-based carbon emissions (TBCE) is found to be insignificant. In contrast, foreign direct investment (FDI) consistently drives emission reduction. A 1% rise in FDI leads to a 0.14% short-term and 0.17% long-term decline in TBCE. These results highlight FDI's role in shaping greener emissions trajectories, aligning economic growth with emissions mitigation. On the other hand, industrialization's lack of significance suggests a nuanced relationship between industrial growth and carbon emissions. The results align with those of Pata and Isik, (2021); Wang et al., (2022) indicated that industrialization and FDI have an important role in the environment. External conflict and international tourism outcomes demonstrate no significant impact on TBCE in Pakistan. These non-significant findings emphasize the need for nuanced approaches when considering these variables in the context of emissions trends. While external conflict and tourism play distinct roles, their direct influence on carbon emissions appears limited within Pakistan's environmental context. In conclusion, these results guide policy considerations for environmental responsibility, underscoring the importance of strategic FDI attraction and mindful industrialization to achieve greener emissions pathways.

The diagnostic test results, meticulously detailed in Table 6, strongly validate the robustness of the ARDL estimation. These tests confirm the presence of serial correlation, normality, and heteroscedasticity results, solidifying the credibility of our approach.

Furthermore, the compelling evidence from the CUSUM and CUSUMSQ statistics plots in Figs. 15, 16 for (model 1 and model–2) reinforces our confidence. These plots notably remain well within the critical limit, underscoring the ARDL estimations' exceptional stability.

Table 6 Diagnostic analysis

Diagnostic test	Model–1 (*P*-value)	Mode–2 (*P*-value)	Decision (H_1)
Breusch-Godfrey LM	0.15	0.24	(×)
Breusch-Pagan-Godfrey	0.74	0.57	(×)
Ramsey RESET test	0.91	0.89	(×)
Jarque–Bera test	0.94	0.78	(×)

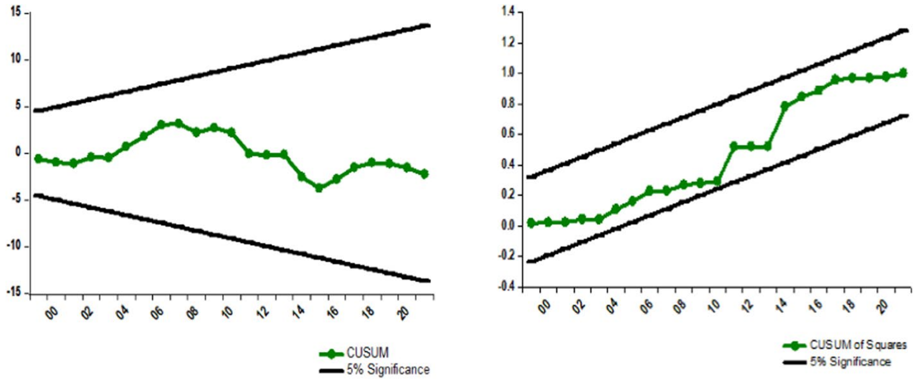


Fig. 15 CUSUM and CUSUMSQ (Model-1)

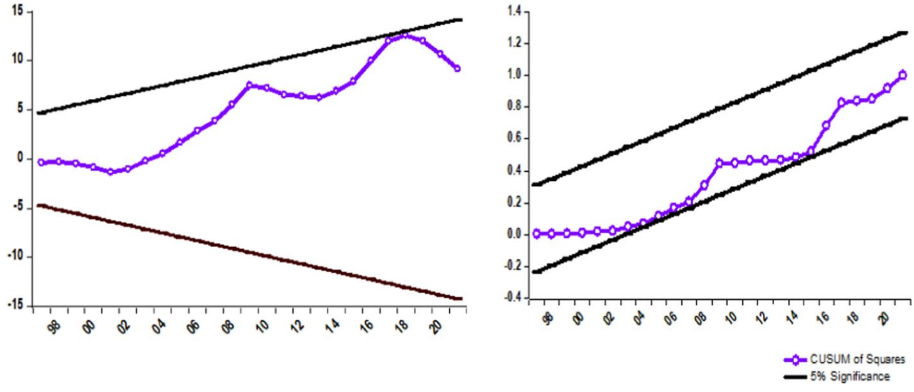


Fig. 16 CUSUM and CUSUMSQ (Model-2)

4.3 Single fourier-frequency toda & yamamoto causality test

The investigation of causal relationships between variables is conducted utilizing the methodologies put forth by Toda and Yamamoto, (1995) (hereinafter referred to as SFTY), along with their recently revised version that incorporates the concept of cumulative Fourier frequency as formulated by Nazlioglu et al., (2016), (2019) (hereinafter referred to as CFTY). The outcomes from both SFTY and CFTY are compared for more robust results.

Notably, the outcomes for SFTY model–1 and model–2 pertaining to the causal relationship are succinctly outlined in Table 7. The findings of model 1 observe that institutional quality, internal conflict, and industrialization establish a unidirectional causal connection with consumption-based carbon emissions, which highlights the potential influence of these factors on environmental sustainability. This suggests that efforts to enhance institutional quality, mitigate internal conflicts, and implement sustainable industrial practices could contribute to a reduction in carbon emissions stemming from consumption patterns.

On the other hand, GDP, FDI, EC, and IT are characterized by a bidirectional causal correlation with the consumption of carbon-based emissions. Similarly, it implies a complex interplay between GDP, foreign investment, geopolitical dynamics, and tourism activities Zhou et al., (2018). The significance of the outcomes gleaned from the analysis, as mentioned earlier, holds considerable importance within the realm of policy formulation and sustainable development strategies for Pakistan.

In the context of model–2, IQ and IT exhibit a unidirectional causal connection with TBCE. IQ refers to the effectiveness, efficiency, and transparency of institutions within a country. For instance, improvements in governance, regulations, and policies might lead to a reduction in carbon emissions as environmentally conscious practices are promoted. At the same time, IT causal connection with TBCE implies that variations in IT have an impact on carbon emissions within the country's territory. This could indicate that changes in tourism patterns, such as an increase in sustainable tourism practices, might contribute to lower carbon emissions Raza Syed and Bouri, (2021).

Additionally, IC, GDP, IND, FDI and EC are characterized by a bidirectional causal correlation with TBCE. IC bidirectional causal correlation suggests a mutual influence on emissions. However, GDP bidirectional causal correlation with TBCE could lead to increased carbon emissions due to higher industrial and consumption activities. Similar to GDP, industrialization is bidirectional correlated with territory-based carbon emissions.

Table 7 Causality test results

Causal relation (Model–1)	Single Fourier-frequency Toda & Yamamoto causality test							
	Wald stat	*p*-value	Lags	F	Causal relation (Model–2)	Wald stat	*p*-value	lags	f
CBCE → IQ	14.24	0.08***	8	1	TBCE → IQ	2.98	0.94	8	2
IQ → CBCE	5.35	0.72	8	1	IQ → TBCE	42.91	0.00***	8	2
CBCE → IC	5.82	0.67	8	1	TBCE → IC	68.13	0.00***	8	1
IC → CBCE	35.00	0.00***	8	1	IC → TBCE	36.45	0.00***	8	1
GDP → CBCE	22.24	0.00***	8	1	GDP → TBCE	16.42	0.04***	8	1
CBCE → GDP	20.51	0.00***	8	1	TBCE → GDP	18.66	0.02***	8	1
IND → CBCE	12.15	0.05**	6	1	IND → TBCE	16.68	0.03***	8	3
CBCE → IND	1.22	0.98	6	1	TBCE → IND	112.24	0.00***	8	3
FDI → CBCE	71.02	0.00***	8	1	FDI → TBCE	31.17	0.00***	8	1
CBCE → FDI	25.91	0.00***	8	1	TBCE → FDI	35.31	0.00***	8	1
EC → CBCE	41.89	0.00***	8	1	EC → TBCE	40.60	0.00***	8	2
CBCE → EC	84.17	0.00***	8	1	TBCE → EC	101.57	0.00***	8	2
IT → CBCE	458.22	0.00***	8	2	IT → TBCE	11.94	0.15	8	3
CBCE → IT	16.31	0.04**	8	2	TBCE → IT	167.82	0.04**	8	3

***, ** and * indicate 1, 5, and 10% significant level

The growth of industrial activities could contribute to higher emissions, and emissions might also influence industrialization trends through environmental policies and practices Ahmed et al., (2021).

FDI bidirectional causal correlation suggests that FDI and carbon emissions have a mutual impact on each other. FDI might influence carbon emissions through investments in industries, technology transfer, and economic activities, while carbon emissions could also influence the attractiveness of the country to foreign investors Rej et al., (2022). Though, EC bidirectional causal correlation indicates that EC and carbon emissions have a reciprocal relationship. The implications of these outcomes are significant for policymakers, indicating the need for comprehensive strategies that address not only environmental concerns but also economic growth, governance, conflict resolution, and tourism practices. It underscores the interconnectedness of various factors in shaping a country's carbon emissions profile and emphasizes the importance of considering these relationships when designing sustainable development plans and policies.

4.4 Cumulative fourier-frequency granger causality test

Conversely, the outcomes obtained through CFTY manifest notably substantial and statistically significant causal relationships across a significant portion of the pairings in Table 8. In the context of model–1 and the Cumulative Fourier-frequency Granger Causality Test, IQ and GDP unveil a unidirectional causal connection with CBCE. The unidirectional causal relationship means that governance, regulatory systems, and policies may affect consumption-related carbon emissions. Higher GDP may boost consumption, which may raise carbon emissions owing to industrial and energy needs. Besides that, FDI, EC and IT are characterized by a bidirectional causal correlation with CBCE in Pakistan. These

Table 8 Causality test results

Causal relation (Model–1)	Cumulative Fourier-frequency granger causality test							
	wald stat	*p*-value	Lags	F	Causal relation (Model–2)	Wald Stat	*p*-value	lags	f
CBCE→IQ	96.24	0.00***	8	3	TBCE→IQ	376.37	0.00***	8	3
IQ→CBCE	7.11	0.53	8	3	IQ→TBCE	389.10	0.00***	8	3
CBCE→IC	10.04	0.26	8	3	TBCE→IC	528.17	0.00***	8	3
IC→CBCE	9.64	0.29	8	3	IC→TBCE	27.86	0.00***	8	3
GDP→CBCE	73.71	0.00***	8	3	GDP→TBCE	69.79	0.00***	8	3
CBCE→GDP	1.65	0.99	8	3	TBCE→GDP	7.51	0.48	8	3
IND→CBCE	4.79	0.78	6	3	IND→TBCE	20.22	0.01**	8	3
CBCE→IND	2.66	0.95	6	3	TBCE→IND	22.23	0.00***	8	3
FDI→CBCE	15.92	0.04**	8	3	FDI→TBCE	11.18	0.19	8	3
CBCE→FDI	23.09	0.00***	8	3	TBCE→FDI	25.77	0.00***	8	3
EC→CBCE	37.98	0.00***	8	3	EC→TBCE	87.28	0.00***	8	3
CBCE→EC	140.39	0.00***	8	3	TBCE→EC	136.62	0.00***	8	3
IT→CBCE	45.73	0.00***	8	3	IT→TBCE	164.96	0.00***	8	3
CBCE→IT	825.72	0.04**	8	3	TBCE→IT	820.92	0.00***	8	3

***, ** and * indicate 1, 5, and 10% significant level bidirectional causal correlations underscore the complexity of the relationships between FDI, EC, IT, and CBCE. It emphasizes that changes in any of these variables can have a reciprocal impact on the others. As such, addressing carbon emissions in the context of consumption patterns requires a comprehensive approach that considers economic, geopolitical, and environmental factors.

Additionally, Table 8 (model–2) CFTY causality test, GDP and FDI revelation a unidirectional causal connection with TBCE. These unidirectional causal connections highlight the role of economic factors, particularly GDP and foreign direct investment, in shaping the carbon emissions landscape within a country's territory. As economic activities and investment patterns change, they can trigger shifts in energy consumption, production methods, and other carbon-emitting activities. Further, model–2 exhibits a bidirectional causal link between IQ, IC, IND, EC and IT with TBCE. These bidirectional causal links underscore the intricate relationships between various socioeconomic factors and territory-based carbon emissions. They highlight how changes in institutional quality, conflict dynamics, industrialization, geopolitical situations, and tourism patterns can lead to changes in carbon emissions and vice versa. To address emissions reduction and environmental sustainability, policies need to consider these multidimensional relationships and balance economic, social, and environmental objectives.

4.5 Discussion

Model–1: the ARDL outcomes unveil vital insights into the environmental dynamics of Pakistan. The effect of institutional quality (IQ) on consumption-based carbon emissions (CBCE) is considerable, leading to a decrease of − 0.90% in the short-term and − 1.22% in the long-term, thereby verifying our hypothesis. This underscores the potential of effective governance for greener practices. Conversely, internal conflict leads to detrimental outcomes, with a 1% increase resulting in a short-term rise of 0.13% and a long-term increase of 0.17% in consumption-based carbon emissions (CBCE), thus confirming our hypothesis. Such findings emphasize the imperative of conflict resolution for environmental mitigation Li et al., (2021).

The impact of economic expansion on emissions reveals a complex and subtle connection. The expansion of GDP is linked to a direct increase of 1.15% and a long-term rise of 1.57% in carbon emissions based on consumption, verifying our hypothesis. Balancing economic advancement with emissions reduction strategies remains critical. Industrialization and FDI consistently demonstrate emission reduction effects. A 1% increase in these factors leads to a 0.23% short-term and 1.08% long-term decline in consumption-based carbon emissions (CBCE). Therefore, industrialization contradicts our hypothesis, while FDI confirms it. Effective industrial policies and foreign investment attraction can foster greener practices Çıtak et al., (2021). External conflict and international tourism outcomes have insignificant CBCE impact, highlighting the role of context-specific factors. In crafting policies, these outcomes underline the need for tailored strategies to ensure sustainability. In sum, these findings guide informed policy decisions. Fostering institutional quality, conflict resolution, sustainable economic growth, and strategic industrial and investment practices emerge as key components in Pakistan's journey toward environmental responsibility.

Model 2: the insights derived from the analysis of territory-based carbon emissions (TBCE) and their associations with distinct variables provide valuable direction for environmental policies in Pakistan. Improved institutional quality (IQ) has a clear and undeniable effect on reducing TBCE, both in the short term 0.92% and in the long term 1.12%, thereby validating our initial framework. This highlights the capacity of strong governance to advance environmental accountability. In contrast, internal conflict stimulates an increase in TBCE, where a 1% increase results in a 0.14% (short-term) and 0.17% (long-term) rise, so confirming our theory. Addressing disputes is not only crucial for social reasons but also essential for environmental mitigation Ramzan and Hossain, (2024). The link between GDP and TBCE is complex, with a short-term rise of 1.18% and a long-term 1.43%, which supports our hypothesis. Ensuring that development is aligned strategically with carbon reduction is of utmost importance. However, FDI consistently decreases TBCE, with a 1% increase in FDI resulting in a short-term reduction of 0.14% and a long-term 0.17%. These findings validate our hypothesis and highlight the significant role of investment in promoting environmentally-friendly projects. The low direct impact of external conflict and tourism on emissions trends in Pakistan is shown by their insignificance and lack of influence on the TBCE.

Overall, the outcome suggests that environmental policy must emphasize institutional quality improvements, conflict resolution, and emissions-conscious growth. Strategic investments and sustainable tourism approaches are pivotal. Integrating these insights into policy strategies can steer Pakistan toward environmentally responsible and sustainable development. In sum, these findings provide a comprehensive view of variable impacts on TBCE, offering critical directions for shaping Pakistan's environmental future.

5 Conclusion and policy recommendations

The main objective of this research is to evaluate the influence of various factors on carbon emissions in Pakistan between 1990 and 2021. To bolster the credibility of the research, the study used the ARDL model, conducted single-Fourier-frequency Toda and Yamamoto Causality tests, and conducted Cumulative Fourier-frequency Granger Causality tests. The results show a clear and noticeable trend; for instance, enhanced institutional quality, industrialization, and foreign direct investment are linked to decreased emissions depending on consumption and territory, both in the short and long term. In contrast, increased levels of internal conflict and GDP are directly linked to higher short- and long-term emissions. These results provide valuable strategic insights that may be applied to other developing economies. Countries such as Pakistan may connect with the broad ambitions of the Sustainable Development Goals (SDGs) by adopting environmental sustainability with economic development. By implementing these techniques, we can guarantee that economic progress is aligned with ecological well-being, benefitting not just Pakistan but also other countries working towards sustainable development.

5.1 Policy recommendations

Based on the main findings of the study, some policy suggestions to help Pakistan reach its Sustainable Development Goals (SDGs):

- Leveraging Institutional Quality for Sustainability: Pakistan provides an opportunity to leverage its increasing Institutional Quality for environmental sustainability. By fostering transparent and effective governance practices, Pakistan can ensure that the economic projects undertaken are aligned with emissions reduction goals, thereby contributing to SDG 16 (Peace, Justice, and Strong Institutions).

- Strategic Investment in Sustainable Industrialization: Recognizing the inverse relationship between Industrialization and emissions, Pakistan can strategically channel the benefits of industrial growth into sustainable pathways. Also, projects could emphasize the establishment of eco-friendly industries and adherence to stringent emissions standards, aligning with SDG 9 (Industry, Innovation, and Infrastructure) and SDG 12 (Responsible Consumption and Production).
- Foreign Direct Investment for Green Development: With Foreign Direct Investment as a potential driver of emissions reduction, Pakistan can attract investments that align with its sustainability goals. By encouraging foreign investors to prioritize projects cantered on renewable energy, green technologies, and environmentally conscious practices, Pakistan can contribute to SDG 7 (Affordable and Clean Energy) while reaping economic benefits.
- Mitigating Internal Conflict for Environmental Prosperity: The study's revelation regarding the adverse effect of Internal Conflict on emissions underscores the importance of stability. Pakistan's commitment to the SDGs initiative could be a catalyst for internal harmony, fostering an environment conducive to sustainable development. A peaceful nation can better channel its resources towards emissions reduction and align with SDG 16 (Peace, Justice, and Strong Institutions).
- Balancing GDP Growth with Carbon Mitigation: Acknowledging the impact of GDP growth on emissions. While economic advancement remains vital, there is an opportunity to prioritize low-carbon and green growth strategies, consistent with SDG 8 (Decent Work and Economic Growth) and SDG 13 (Climate Action).
- Policy Alignment for Sustainable Development: Pakistan's policy alignment between economic endeavours and emissions reduction may incorporate sustainability considerations into policy frameworks; Pakistan can showcase its commitment to SDG 17 (Partnerships for the Goals), fostering collaboration among nations for a sustainable future.
- Monitoring and Reporting Mechanisms: The study's findings on emissions dynamics call for robust monitoring mechanisms. Pakistan could advocate for standardized reporting of emissions reduction efforts, enhancing transparency and accountability among participating countries, aligned with SDG 12 (Responsible Consumption and Production) and SDG 16 (Peace, Justice, and Strong Institutions).
- Promotion of Green Tourism: Highlighting the positive impact of foreign tourism on emissions reduction, Pakistan can collaborate with other countries to promote sustainable tourism practices. This initiative contributes not only to economic growth but also to SDG 12 (Responsible Consumption and Production) and SDG 8 (Decent Work and Economic Growth). By aligning these suggestions with the main findings of the study, Pakistan can effectively harness its potential to catalyse emissions reduction, contribute to the SDGs, and foster a sustainable future.

5.2 Limitation of the study and future direction

While this study provides valuable insights into the relationship between socioeconomic factors and carbon emissions in Pakistan within the framework of Sustainable Development Goals (SDGs), it is important to acknowledge several limitations. To address these limitations and further advance understanding in this area, future research could consider the following directions. Conducting longitudinal studies with more extensive data coverage could provide a more comprehensive understanding of the evolving relationship between socioeconomic factors and carbon emissions over time. This would enhance the robustness and reliability of the findings.

Appendix

See Fig. 17 and Table 9.

Fig. 17 Correlation matrix

Table 9 Nomenclatures

AMG	Augmented mean group	4
ARDL	Autoregressive distributed lag	2
CBCE	Consumption-based carbon emissions	2
CCEMG	Common correlated effects mean group	4
CFTY	Cumulative fourier-frequency granger causality	2
CS-ARDL	Cross-sectionally augmented autoregressive distributed lag	4
EC	External conflict	2
EKC	Environmental kuznets curve	3
FDI	Foreign direct investment	2
GMM	Generalized method of moments	5
IC	Internal conflict	2
IND	Industrialization	2
IQ	Institutional quality	2
IT	International tourism	2
KRLS	Kernel regularized least squares	4
MENA	Middle east and north africa	5
NRC	Nonrenewable energy consumption	4
PCO2	Production-based emissions	5
R&D	Research and development	5
RE	Renewable energy consumption	3
SDGs	Sustainable development goals	1
SFTY	Single-fourier-frequency toda & yamamoto causality	2
TBCE	Territory-based carbon emissions	2
TCIS	Tourist carbon information system	4
VECM	Vector error correction modeling	4

Author's contribution N.F. (Firdous) and K. R. A. (Abbasi) has contributed to the idea conceptualization of the study, design, analysis, and conclusion. Reviewed edited manuscript and approved the final submission. A. S. (Salman) supervision and conclusion. Reviewed the edited manuscript and approved submission. C. S. (Sahin) conceptualizes the study, software data curation, and literature search A. H. (Hamza) review and editing.

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Declarations

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