Decomposing the effect of trade on environment: a case study of Pakistan

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Received: 20 September 2021 / Accepted: 14 January 2022 / Published online: 12 August 2022
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Abstract
Using time-series data from 1984 to 2019, the study examines the vigorous trade-environment relation in Pakistan. Pakistan is an interesting case study in which trade liberalization has expanded economic activity while also increasing environmental pollution during the last two decades. As a result, determining whether trade and industrial operations have contributed to environmental degradation is crucial. Our first goal is to look at how trade affects the environment in terms of scale, composition, and technique. The second step is to look into the pollution haven theory. The study uses a new approach to measuring trade openness called composite trade intensity, which differs from the traditional approach. The dynamic autoregressive distributed lag (ARDL) simulation framework, which was recently developed, was employed. The findings show that the scale impact raises CO2 emissions while the technique effect helps to lessen them, proving the existence of an environmental Kuznets curve (EKC) hypothesis. The composition impact contributes to increased pollution in the environment. Through the expansion of pollution-intensive export businesses, trade openness degrades environmental quality over the long as well as in the short term. The notion of a pollution hypothesis has also been proven. The quality of the environment deteriorates as a result of urbanization, whereas it improves as a result of good governance. Economic growth, trade openness, urbanization, and CO2 emissions have bidirectional causality, according to frequency domain causality findings. Based on our empirical findings, the study concludes that individual efforts, as well as collective efforts at the international level to reduce carbon emissions, are critical to solving the problem of environmental degradation and making the world a completely peaceful place.

Keywords Scale effect · Composition effect · Technique effect · Environmental pollution · Error Correction model etc.

Jell Classification Codes F18 · Q56 · Q3

Introduction
Globalization has increased the volume of trade between countries as well as the worldwide export-to-GDP ratio. More investment, job, and income prospects have benefited the countries as a result of trade (Zahonogo 2017). Other advantages include labor and capital mobility, ease of movement of goods and services, information, norms, and values dispersion, and so on. Liberalization opponents say that the benefits of liberalization have worsened the economic divide between the South and the North. The benefits of liberalization have always been highlighted, but the fundamental drawback, namely the environmental issue, has usually been overlooked. Developing countries, in general, face the concern of environmental problems as a result of weak infrastructure, regulatory framework, and lack of awareness (Malefane and Odhiambo 2018). Industrial activity has increased as a result of globalization, which has coincided with strong economic growth. These countries specialize in the manufacture of polluting or unclean goods.

Globalization influences the environment through technique, composition, and scale effect, according to economic research (Antweiler, et al. 2001). According to the scale effect, pollution is caused by a growth in the scale of economic activity, which includes both consumption and production (Cole 2006). Globalization raises the demand for goods and services on a worldwide scale. The technique
impact explains the use of different manufacturing processes as a result of increased economic growth (Antweiler et al. 2001; Dollar and Kraay 2004). The composition effect is what explains how trade changes the structure of goods. Because of the weak regulatory framework, developing countries have specialized in the production of pollution-intensive objects as a result of trade (Stern 2007). They also draw pollution-producing industries from throughout the world. This is how polluting industries migrate to underdeveloped countries, resulting in the pollution haven hypothesis (Copeland and Taylor 1995; Solarin et al. 2017).

Free trade proponents claim that decreasing trade barriers makes it easier to transfer green technology, knowledge, and other management approaches between countries. As a result, trade boosts the positive technique effect, which outweighs the negative scale effect. It is also said that openness causes a favorable composition effect because of more income. By reducing the need for dirty items, more income as a result of trade openness promotes demand for cleaner products and production practices (Shafik and Bandyopadhyay 1992).

According to conflicting studies, trade openness is a two-edged sword that offers both opportunities to reduce pollution and risks of increasing pollution (Mapapu and Phiri 2018; Inglesi-Lotz 2018; Copeland and Taylor 1995). It all depends on the efficient use of resources as a result of free trade. There are opportunities for secure technology transfer and economic progress. Along with economic progress, governments must enact policies to protect the environment. Because of a lack of financial resources and political constraints, policy implementation is a difficult challenge for developing countries. In developing countries, the government’s goal is to boost economic growth at the expense of the environment.

Pakistan’s industrial performance has been inconsistent over the years. During the 1960s, it was up to par, but due to the government’s nationalization effort in the 1970s, the situation reversed. Domestic enterprises were given extensive protection, allowing them to operate without fear of foreign competition, which hampered output. As a result of the failure of the import substitution and high tariff strategy in the 1960s and 1970s, liberalization measures in the 1980s were implemented (Azhar et al. 2007; Qureshi 2006). As a result of trade reforms, the economy has become more open, with fewer trade restrictions, lower tariffs, and fewer non-tariff obstacles. In the early 1980s, exports covered half of the import cost, but later on, export performance improved. The economy was doing well until the 1990s, when it hit a snag owing to political unrest and poor law and order. The pace of manufacturing and trade has slowed. Liberalization policies combined with a structural adjustment program worked successfully in the late 1990s. Exports were diversified, and exporters were given access to infrastructure. Import restrictions were removed, and the trade balance improved. During the 2000s, Pakistan pursued an export-led strategy that gave it increased access to the international market for its goods (Ahmed and Long 2012).

Before the 2019 coronavirus epidemic, the economy was doing well (COVID-19). The supply-side and commercial operations were disrupted by preventive measures against the (COVID-19), such as lockdown, inter-city and inter-country limitations, and social isolation. Despite government efforts to lower tariffs on industrial inputs, continuous currency depreciation over the last two years has curtailed imports. Pakistan’s government is currently pursuing bilateral free trade agreements with its neighbors. However, the impact of these agreements on the environment is not the primary issue.1 According to the World Bank, trade’s proportion in the global economy has more than doubled since 1960. At the same time, trade liberalization has resulted in a 73% increase in carbon dioxide emissions (Zhang et al. 2017). Due to the internal and external environment, Pakistan’s export sector has had a mixed record. China is a major trading partner that has a significant impact on industrialization, technology, and infrastructure development.2 Pakistan’s main export partners are the UK ($1.63 billion), China ($1.50 billion), Germany ($1.28 billion), and Spain ($0.9 billion), while its main sources are China ($16.89 billion), the United Arab Emirates ($8.39 billion), the USA ($6.40 billion), Saudi Arabia ($3.06 billion), and Japan ($2.51 billion) (Yeo and Deng 2019).

In terms of Pakistan’s environmental issues, the country’s high population growth rate (3 percent per year), average yearly GDP growth rate (4.5% per year), and urbanization have all put a strain on the country’s natural resources (Qureshi 2006). The industrial sector, autos, home, and industrial wastewater, deforestation, and waterlogging, among other things, are major contributors to environmental pollution. Industrial activities are concentrated in metropolitan areas, which pollute the water and air with industrial waste. These industrial clusters are formed without any planning, and businesses lack the necessary facilities to appropriately dispose of industrial waste. Humans, animals, and marine life are all harmed when waste is dumped into rivers, canals, and agricultural land. For example, industries are constructed along the coastal area in Karachi, which is an industrial center with a population of more than 10 million people. Industrial waste in the form of poisonous compounds is discharged into rivers and the sea, posing a threat to the fishing industry. This effluent

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1 International Trade in Goods and Services in Pakistan: Overview.
2 M. S. Irshad. “One Belt and One Road: Does China-Pakistan Economic Corridor. Benefit for Pakistan’s Economy?” (2015).
is hazardous to human health, and water-borne infections account for about 40 to 50 percent of all deaths in Pakistan. In other sectors of the country, the situation is similar.

Energy consumption and carbon dioxide emissions are expanding dramatically as the industrial and power sectors expand. Pakistan has a greater emission intensity than the rest of the globe. Carbon dioxide emissions, as well as the consumption of gas, electricity, petroleum, and crude oil, have all increased on average. According to the British Petroleum review report, carbon dioxide emissions per capita have increased by 8.5 percent in Pakistan, 6.3 percent in Malaysia, 7.6 percent in Indonesia, 8.2 percent in Ukraine, and 5.2 percent in Turkey. Pakistan contributes significantly to carbon dioxide emissions among the 196 countries, emitting 192.7 million tonnes each year. From 1999 to 2018, Pakistan was the fifth country to be hit by extreme climate change events, resulting in a 2.8 billion dollar economic loss. (Ahmed, et al. 2020a, b).

Economic growth brings benefits to ordinary people in the form of increased wealth, but it also deteriorates the atmosphere, as the environmental Kuznet curve explains. In order to strengthen the economy, a country must sacrifice the environment. Since the 1990s, economists such as [Grossman and Krueger (1995), Shafik and Bandyopadhay (1992), Panayotou (1993), Selden and Song (1994)] have used the environmental Kuznets curve to support the EKC hypothesis.

The Pakistan Environmental Protection Act (PEPA) was enacted in 1997 to keep track of environmental protection in the country’s provinces. However, because of budgetary and political constraints, enforcement is severely hampered.

In light of the abovementioned, the study explores the impact of trade openness on the environment in Pakistan using the scale, technique, and composition effects. Second, it investigates the pollution haven hypothesis. Finally, policy recommendations are made based on empirical findings in order to mitigate these effects. We employed a new trade intensity measure that differs from the usual approach. Furthermore, we applied the most recent econometric technique, novel dynamic ARDL simulation. Future researchers will be able to undertake a similar study for different countries based on the findings of this study. Previous research in this area has primarily relied on cross-country analysis, which is sensitive to the pollutants chosen and the countries included in the sample. Because countries differ in size, location, and characteristics, etc., the focus has recently shifted to individual country analysis so that sound policy recommendations may be provided based on those qualities. Pakistan is an excellent case study since there is little research that looks at the indirect effects of trade on the environment, while most studies look at the direct effects of trade openness on the environment. In the early 1990s, Pakistan proceeded toward trade liberalization, which resulted in greater economic activity and, at the same time, increased environmental pollution during the last two decades. As a result, it is critical to determine if trade and industrial operations have contributed to environmental damage.

The study is divided into five main sections. The first section is a brief introduction that outlines the study’s motivation, contribution, and goals. The second section examines the review of prior studies as well as the gap in the literature. The third section covers the model’s theoretical framework, variable descriptions, and methods. The fourth section presents the findings of our empirical analysis, while the fifth and final sections examine the findings, policy recommendations, and future research prospects.

Literature review

This section discusses the overview of preceding literature on trade and environment. The earlier work done on trade and environment summarize in this literature.

From 1972 to 2013, Ampofo et al. (2021) investigate the asymmetric influence of economic expansion on the environment for the next 11 countries. Along with nonlinear causality, a nonlinear autoregressive distributed lag model is used. Carbon dioxide emissions rise as the economy grows. The amount of CO2 emitted increases as energy usage rises. In Bangladesh and Iran, long-run and short-run asymmetry between energy use and CO2 emissions has been demonstrated. In Bangladesh and Turkey, there is evidence of bidirectional causality between economic growth and CO2 emissions, but in Egypt and South Korea, there is evidence of unidirectional causality between economic growth and CO2 emissions. In Bangladesh, Egypt, Pakistan, and South Korea, there is a causal relationship between energy usage and carbon emissions.

For the Southern African Development Community (SADC), Udeagha and Breitenbach (2020) looked at the relationship between trade openness and carbon dioxide emissions from 1960 to 2014. The Dynamic Ordinary Least Squares findings are intriguing in that they show that trade openness lowers carbon dioxide emissions. The scale effect raises CO2 emissions whereas the technique impact decreases them, proving the EKC hypothesis. The analysis also backs up the pollution haven theory. While the composition impact lowers CO2 emissions, the comparative advantage effect raises them. In terms of other factors such as technological and financial growth and sectoral GDP lower CO2 emissions while energy consumption and governance.
raise them. According to the study, there is a need to invest in new technology.

From 1980 to 2014, Vural Gulfer (2020) explores the link between trade and carbon dioxide emissions in eight Sub-Saharan African countries. Output, renewable energy, and non-renewable energy are all aspects to consider. The panel co-integration methodology of the second generation is applied. Nonrenewable energy and trade openness are found to cause CO₂ emissions, whereas renewable energy benefits the environment. The EKC hypothesis has been proven.

Using the non-linear ARDL technique, Udeagha and Ngepah (2019) examined the trade environment relationship for South Africa from 1960 to 2016. The standard measure was compared to a new one called composite trade intensity. The findings reveal that in the short run, trade openness reduces CO₂ emissions, but in the long run, the opposite is true. Previous investigations have contradicted these conclusions. The pollution haven theory holds true as well. The relationship between trade openness and CO₂ emissions is asymmetric. To reduce CO₂ emissions, trade liberalization and greentech technology are both required. Udeagha and Ngepah (2021a, b) used a new technique, novel dynamic ARDL simulation, to review the trade environment nexus for South Africa from 1960 to 2020. The findings are compared to previous findings. Udeagha & Ngepah (2021a, b) look at the impact of disaggregated renewable and nonrenewable energy use on environmental quality in South Africa between 1960 and 2019. The research makes use of a novel dynamic ARDL simulation. For robustness, the study used the frequency-domain causality (FDC) technique. For robustness, the study employs the second-generation structural break unit root test. The use of hydroelectricity and nuclear energy reduces CO₂ emissions, according to the findings. The scale effect causes CO₂ emissions to increase, but the technique effect causes them to decrease. The usage of oil, coal, and natural gas has a negative impact on the environment. It is advised that the government should use a combination of existing energy resources to meet energy needs and reduce CO₂ emissions.

From 1971 to 2014, Mahmood et al. (2019) investigated the nonlinear influence of trade on the environment and the EKC hypothesis in Tunisia. At a threshold level of income of roughly 292.335 billion US dollars, the EKC hypothesis was proven. The impact of trade on CO₂ emissions is asymmetric. The impact of trade openness, both favorable and negative shock, is found to be positively related to CO₂ emissions. For Tunisia, the pollution haven theory has been proven.

Iorember et al. (2019) used quarterly data from 1990 Q1 to 2004 Q4 to investigate the nonlinear effects of trade openness, renewable energy demand, and economic growth on environmental quality in Nigeria and South Africa. The model utilized is a nonlinear autoregressive distributed lag model. All of the variables, both in the long and short run, exhibit a nonlinear relation with the environment, according to the findings. A negative shock has a longer-term impact on Nigeria than a positive shock. The positive impact of trade liberalization outweighs the negative impact. The positive shock is stronger than the negative shock for South Africa, just as the negative effect of trade openness is stronger than the positive. The study recommends measures that encourage the usage of renewable energy sources.

Using dynamic ARDL models, Khan et al. (2019) investigated the impact of energy consumption and economic growth on carbon dioxide emissions in Pakistan. According to the findings, economic growth, coal, oil, and natural gas consumption all have a positive impact on environmental degradation in Pakistan, both in the short and long term. It has been proposed that increasing renewable energy sources can aid in the reduction of environmental impact.

Sun et al. (2019) examine the relationship between trade and environmental pollution through economic growth and energy usage as central prospective for 49 high emission countries. The study finds reversed U-form relation between trade and CO₂ discharge. The findings of the study show that trade openness has dual effects, positive as well as negative on environmental pollution but the effect varies in nations. Duodu (2018) examined the trade environment relationship through technique and scale effect. The results show that emission increases with higher growth and falls with development. Gill et al. (2018) tested the pollution haven proposition. The study asserts that developing countries have become the pollution haven for developed countries. Findings show that foreign direct investment more pollutes the environment due to increased industrialization. Tariq et al. (2018) observed the relationship between FDI and trade with environmental quality in Pakistan and India. It is concluded that foreign direct investment damages the atmosphere of both countries Crestia and Cherniwchan (2017) examined the relationship between international trade and emission that comes from the transport of traded goods. It is concluded that emission-reducing trade is occurring in the agriculture and mining sector. Hu and McKitrick (2016) analyzed the influence of open trade policy on pollution. The study observed that trade liberalization increases the domestic production and decreases consumption of environmentally harmful goods simultaneously. Results support the pollution haven hypothesis. Riti et al. (2016) observe the effect of FDI inflows and industrialized export on greenhouse emission in Nigeria. The outcome proves the presence of pollution haven proposition whereas a direct relation exists between industrial exports and emission. Twerefou et al. (2016) examined the trade liberalization policies in Ghana. The study aims to find the scale, techniques and composition effect of free trade on Ghana. The study indicates that in the long run scale effect has damaging effect on CO₂ emission.
Alam et al. (2011) tested the long run association among free trade, environmental scarcity and sustainable economic development beside other important socio-economic variables in Pakistan. The results suggest that industrial and agricultural activities and increased urbanization harmfully affect the environment while trade liberalization and human development affect the environment pleasant. Managi et al. (2009) worked on trade openness, economic development and environment. Outcome show that trade is good for the growth of a country but on other hand it also destroys environmental quality. Trade bring benefits for environment in OECD countries and the quantity of emissions are more in non OECD countries. Antweiler et al. (1998) find the relationship between free trade and environment. The study builds up a model that decompose the effect of trade into scale, technique and composition. An assessment of all three effects leads to the surprising outcome that trade is not harmful for the atmosphere.

It is concluded from the review of previous empirical work that there is vast literature available in Pakistan that analyze the direct effect of trade openness on environment. Our study provides an insight regarding the indirect influence that trade has on atmosphere; scale, composition and technique effect.

**Formulation of the model**

This section describes the theoretical framework of the study. We have distributed it into three sections. The theoretical framework is discussed in the first section. The description of variables is discussed in the second section while last section represents methodology.

**Theoretical framework**

Following Antweiler et al. (2001) and Cole and Elliott (2003), the study provides us a model that allows us to split the effect of trade into scale, technique and composition. The study describes a model where two ultimate goods (X and Y) are made, in a small open economy, having two inputs, human capital (K) and natural capital (N). We suppose good Y is human capital intensive creating no pollution while good X is natural capital intensive and will be the cause of pollution creation. Constant returns to scale are also supposed here. The link between environmental deterioration and economic participation is described by a simple emission function.

\[ E = eX = e\theta S \]  

Here e represents the pollution concentration of bad industry, \( \theta \) describes the portion of X in output and S represents the scale measure. Equation shows that total amount of emission (E) is determined by the pollution concentration of the bad industry e, the comparative significance of dirty industry \( \theta \) and the total scale of economy S. Therefore, we can also write the above equation in differential form as:

\[ \frac{\Delta E}{\Delta S} = \frac{\Delta S}{\Delta S} + \frac{\Delta \theta}{\Delta S} \]

Scale effect is denoted by the first term on right hand side of the equation which indicate the increase in the output due to higher trade and resultant effect on emission. Here the hat specifies percentage change. Thus, keeping constant the production techniques e and mix of goods produced \( \theta \), environmental destruction is supposed to increase as the scale of economic action increase. The composition effect is represented by the second term, which represents the effect of change in structure of the output on the environment. An economy that allocates more of its assets towards harmful good X, will damage the atmosphere further, holding constant the scale of the economy. Technique effect is represented by the last term in equation. Ceteris peribus, a decrease in the concentration of emission will decrease pollution.

We formulate our empirical model based on above equation:

\[ E_t = B_o + B_1X_t + \epsilon_t \]  

Here \( E_t \) denotes carbon dioxide emission, \( X_t \) represents the vector of explanatory variables; the scale effect, composition effect and technique effect. \( \beta_1 \) represent the coefficients to be measured, \( \epsilon_t \) is the white noise error postulate to be normally distributed.

We introduce some other explanatory variables that are relevant to economic literature (Antweiler et al. 2001). Trade openness is included to see the effect of trade intensity. McCarney et al. (2005) emphasize that environmental quality is affected by urbanization. Governance is included in the analysis to investigate how regulatory policies deal with the environment. CO₂ emission is used as a variable that pollutes the environment.

The modified model is specified below;

\[ E_t = a_0 + a_1Y_t + a_2Y^2_t + a_3(K/L)_t \]
\[ + a_4TO_t + a_5URB_t + a_6GOV_t + \mu_t, \]  

\[ a_{1>0}, a_{2<0}, a_{3>0}, a_{4>0}, a_{5>0}, a_{6<0} \]

Where \( E \) is the annual production of CO₂ emissions in metric tons per capita. Carbon emission depends on real GDP per capita (Y) and its square, capital labour ratio (K/L), trade openness (TO), urbanization (URB) and governance (GOV). Y and its square comprise the scale and technique.
effect respectively while $K/L$ denotes to composition effect. $\mu_{1t}$ is the error term having constant variance and zero mean.

Economic literature ascertains that the government policy of environmental regulations can alter the trade environment linkage “pollution haven proposition.” With the intention to observe the pollution haven effect, we estimate the following equation.

$$E_t = \beta_0 + \beta_1 TO_t + \beta_2 (TO'RI_t) + \beta_3 (TO'RI_t^2) + \beta_4 URB_t + \beta_5 GOV_t + \mu_{1t} \quad (5)$$

$\beta_1 > 0, \beta_2 > 0, \beta_3 < 0, \beta_4 > 0, \beta_5 > 0, \beta_5 < 0$

Haven is represented by the collaboration of trade openness and relative income and also square of relative income is interacted with trade openness. Relative income is the per capita income in terms of world average. $\mu_{2t}$ is the error term.

**Measurement of trade openness**

Following Udeagha & Ngepah (2019, 2021a, b), the composite trade intensity (CTI) established by Squalli and Wilson (2011) is used in the study to overcome the constraints of the traditional trade intensity used in the prior literature. It is the trade intensity adjusted by the fraction of a country’s trade volume in global trade volume. It is unique in that it encompasses two facets of a country’s international ties. The CTI is provided in this manner.

$$CTI = \frac{(X + M)_i}{\sum_{j=1}^{n} (X + M)_j} \frac{(X + M)_j}{GDP_i}$$

Here $i$ stands for Pakistan and $j$ for its trading partners; the former half of the equation reflects world trade share, while the latter half shows Pakistan’s trade share.

**Description of variables**

We have used annual data for Pakistan from 1984 to 2019. There are different sources of data used. These include; World Development Indicators (WDI), International Country Risk Guide (ICRG) and Pen World Tables (PWT). All the variables are converted to logarithms before analysis.

Carbon di oxide ($CO_2$) is taken in metric tons per capita from WDI. $CO_2$ emissions are fossil fuels which include emission through ingestion of solid, liquid, gases and fuels. The scale and technique effect is measured by real GDP per capita and its square respectively. Data is taken from WDI in local currency units. The scale effect explains that an increase in production as a result of trade harm the environment therefore the scale effect is probable to be negative. The technique effect denotes that the propensity for emission intensity decrease as income levels increase through enlarged trade. The coefficient of technique effect is anticipated to be negative. The composition effect is measured by the capital-labor ratio. Data of capital stock and labour force is taken from PWT. The composition effect denotes the variation in emission release brought by changes in a country’s composition of output. Trade liberalization brings a change in the structure of output of a country according to the comparative advantage. If a country has comparative advantage in environmentally harmful goods, trade would indorse such production, thereby growing the emission. The coefficient of capital-labor ratio is probable to be positive.

The variable trade openness is measured as composite trade intensity, which is calculated by adjusting the trade intensity by the proportion of a country’s trade volume relative to global trade volume. The theory predicts that trade openness increases the $CO_2$ emissions in low income countries. Trade openness lead firms to increase their production scale, which raises the emissions activities. Urbanization is simply measured by the urban population as a fraction of total population, is taken from WDI. Fast urbanization due to globalization over the last few decades has the potential for increased energy consumption and severe environmental concerns. Urban areas are prone to energy intensive, higher economic activities (i.e., industrial manufacturing and transportation) that cause environmental degradation therefore the coefficient of urbanization is expected to be negative. We have used regulatory quality as an indicator of governance. It shows the formulation and implementation of sound policies. Index ranges between 0 and 6 which shows lower to higher regulatory quality. Data is taken from ICRG. As regulatory quality/governance improves carbon dioxide emission reduce. Governance and carbon dioxide emissions are expected to be inversely related.

Trade openness is interacted with relative income per capita and the square of relative income in order to determine the pollution haven proposition. Relative income per capita is taken relative to the world average data of which is taken from WDI. Pollution haven proposition postulates that a country having relatively low level of income per capital (lax environmental regulations), more openness will make the country dirtier. The linear interaction income is likely to be positive whereas the inverse is expected for quadratic term (Table 1).

**Econometric methodology**

This section ultimately discusses the econometric methodology that is incorporated in the study. The section describes the unit root test, novel dynamic ARDL simulation and frequency domain causality.
Table 1 Description of variables

| Variable name                   | Symbol | Description                                                                 | Source   |
|---------------------------------|--------|-----------------------------------------------------------------------------|----------|
| Carbon Dioxide emission         | $E$    | Quantity of carbon that is quitted from economic activities (metric tons per capita) | WDI      |
| Real GDP per capita             | $Y$    | Country’s output that accounts for its number of people. The scale effect is represented by real GDP per capita | WDI      |
| Squared real GDP per capita     | $Y_2$  | Technique effect is represented by the square of real GDP per capita          |          |
| Capital Labor ratio             | $K/L$  | The capital–Labor ratio measures the composition effect                      | PWT      |
| Urbanization                    | $URB$  | Urban inhabitants as a fraction of total % of total population                | ICRG     |
| Governance                      | $GOV$  | Governance is represented by bureaucratic quality Index (0–10) weak to strong |          |
| Trade Openness                  | $TO$   | Composite trade intensity is used to measure trade openness                   | WDI, Author |
| Relative income per capita      | $RI$   | Income per capita divided by the world average                               | WDI      |

**Unit root test**

We begin the econometric investigation after testing the order of integration among the variables. To test the stationarity of variables we use unit root test. In stationary time series, shocks will be short-term and their effect will be removed gradually as the series go back to their long term average values. In stationary process, all the moments of probability distribution are invariant. Testing unit roots can be done in a variety of ways. Among these are the Dickey and Fuller (1979) (DF) test, the Augmented Dickey and Fuller (1981) (ADF) test, and the Philip and Perron (1988) (PP) test. It is required to run classical regression and determine likely feature of series before performing formal testing.

**Novel dynamic ARDL simulation**

In prior studies of the trade-CO$_2$ emission nexus, the ARDL approach proposed by Pesaran et al. (2001) and other cointegration techniques that can merely assess the short- and long-run relationship between the parameters were extensively used. Jordan and Philips (2018) advanced a new dynamic auto regressive dynamic distributed lag model simulation which effectively solves the problems related to traditional auto regressive dynamic distributed lag approach. The recently advanced technique can simulate and generate graphs of fluctuations in parameters, along with short and long-term association between the variables. A primary advantage of this approach is the ability to anticipate, simulate, and plot the forecast change on a regressand by changing one regressor while keeping the others constant. The variables in the dynamic ARDL simulation process must be cointegrated with a one integration order. The dynamic ARDL in this study performs 5000 simulations. Following Udeagha and Ngepah (2021a) the novel dynamic ARDL simulation model is described in the following manner.

**Equation (4) in the form of dynamic ARDL.**

$$\Delta E_t = \pi_0 + \eta_0 E_{t-1} + \gamma_1 Y_{t-1} + \gamma_2 Y^2_{t-1} + \gamma_3 (K/L)_{t-1} + \gamma_4 (TO)_{t-1} + \gamma_5 (URB)_{t-1} + \gamma_6 (GOV)_{t-1} + \phi_1 \Delta Y_t + \phi_2 \Delta Y^2_t + \phi_3 \Delta (K/L)_t + \phi_4 \Delta (TO)_t + \phi_5 \Delta (URB)_t + \phi_6 \Delta (GOV)_t + v_t$$

In the above equation $\pi_0$ represents error correction term, $\gamma_1 - \gamma_6$ denote the long run estimates, while $\phi_1 - \phi_6$ signify the short-run regressors respectively.

**Equation (5) in the form of dynamic ARDL.**

$$\Delta E_t = \pi_0 + \pi_1 E_{t-1} + \theta_1 \Delta (TO)_t + \theta_2 \Delta (TO) (RI)_{t-1} + \theta_3 \Delta (TO) (RI) (RI)_{t-1} + \theta_4 \Delta (URB)_t + \theta_5 \Delta (GOV)_t + \omega_t$$

Similarly, as in the previous equation $\pi_0$ represents error correction term, $\theta_1 - \theta_6$ denote the long-run estimates, while $\chi_1 - \chi_6$ indicate the short-run regressors respectively.

As a first step we estimate the above equations by choosing the appropriate lag length then we apply the bound test on long-run run parameters. The null hypothesis of no long-run relationship is verified against the alternate. The critical bounds values provided by (Kripfgang and Schneider 2019) are used in this study. When the calculated value of $F$ statistics exceeds the upper bound null hypothesis must be rejected. Then we proceed for the long-run and short-run estimates.

**Frequency domain causality**

To investigate the causal linkages among the variables under consideration, the study utilizes the frequency domain causality technique advocated by Breitung and Candelon (2006). Unlike the usual Granger causality method, which makes it practically difficult to estimate the outcome variable.
at a certain point in time, frequency domain causality allows permanent causality to be documented for the medium, short, and long term among the variables under inquiry. The equation is stated as follows:

\[ X_t = \alpha_1 X_{t-1} + \cdots + \alpha_p X_{t-p} + \beta_1 Y_{t-1} + \cdots + \beta_p Y_{t-p} + \varepsilon_t \]

\( \alpha \) and \( \beta \) are the parameters to be estimated, whereas \( \varepsilon_t \) is an error term. We test the null hypothesis of no causality beside the alternate.

**Results and discussion**

This section describes the empirical analysis. First we describe the descriptive statistics, results of pairwise correlation and stationarity test. Next, we give the lag selection criterion, results of bounds test and diagnostic test statistics. Latter we discuss the results of dynamic autoregressive distributed lag model frequency domain causality.

**Descriptive statistics**

Before the estimation is obligatory to find out whether the data is normally distributed or not. If the value of mean and median are closely related with each other then the data are said to be normally distributed and there is no spread in it. On the other side, standard deviation shows variation in the data if the variation is small it means that data is stable. Our results show that standard deviation of all the variables is small so there is no variation in our data (Table 2).

**Pairwise correlation**

Correlation is a relationship between two explanatory variables. If the value of variables is closely related to zero it means that there is less correlation while if the value is closely related to one it means that there is high

| Table 2 Results of descriptive statistics |
|-------------------------------------------|
| Variables | \( E \) | \( Y \) | \( K/L \) | \( URB \) | \( GOV \) | \( TO \) | \( RI \) |
| Mean | 0.6435 | 0.5864 | 12.9687 | 32.1460 | 5.5790 | 0.250861 | 0.105032 |
| Median | 0.6662 | 0.4973 | 13.1054 | 32.3480 | 5.3800 | 0.226858 | 0.102593 |
| Maximum | 0.9469 | 0.9094 | 14.7899 | 35.8190 | 8.0000 | 0.399375 | 0.135531 |
| Minimum | 0.3318 | 0.3297 | 11.2014 | 28.0660 | 2.4167 | 0.117700 | 0.084134 |
| Std. Dev | 0.1821 | 0.1915 | 1.1568 | 2.3320 | 1.3986 | 0.082225 | 0.014873 |

| Table 3 Results of pairwise correlation |
|------------------------------------------|
| \( Y \) | \( Y^2 \) | \( K/L \) | \( URB \) | \( GOV \) | \( TO \) | \( RI \) |
| \( Y \) | 1 |
| \( Y^2 \) | 0.69514 | 1 |
| \( K/L \) | 0.65711 | 0.152318 | 1 |
| \( NR \) | 0.55566 | 0.556958 | 0.49211 | 1 |
| \( GOV \) | 0.52713 | 0.513993 | 0.41128 | 0.52134 | 1 |
| \( TO \) | -0.41575 | -0.41712 | -0.40565 | -0.3839 | -0.39422 | 1 |
| \( RI \) | 0.56198 | 0.459108 | 0.23138 | 0.64848 | 0.29960 | 0.23343 | 1 |

| Table 4 Results of unit root test |
|----------------------------------|
| Variable | Level | First difference | Order of Integration |
| | ADF | PP | ADF | PP |
| \( E \) | 1.951 (2.941) | 1.914 (2.941) | 6.249* (2.941) | 6.308* (2.943) | I(1) |
| \( Y \) | 0.11 (2.941) | 0.232 (2.941) | 7.312* (2.941) | 7.322* (2.941) | I(1) |
| \( K/L \) | 0.48 (2.941) | 0.489 (2.941) | 5.651* (2.941) | 5.662* (2.941) | I(1) |
| \( URB \) | 0.893 (2.941) | 2.020 (2.941) | 3.87* (2.941) | 3.71* (2.941) | I(1) |
| \( GOV \) | 2.027 (2.941) | 2.198 (2.941) | 4.268* (2.941) | 9.470* (2.943) | I(1) |
| \( TO \) | 1.978 (2.941) | 1.033 (2.941) | 5.479* (2.941) | 5.733* (2.941) | I(1) |
| \( RI \) | 0.968 (2.941) | 0.985 (2.941) | 5.94* (2.941) | 5.496 (2.941) | I(1) |

* denote the significance at 5% level
correlation. In our results there is no problem of multicollinearity (Table 3).

Results of unit root test

We have tested all the variables individually by Augmented Dickey-Fuller (ADF) and Philip Perron unit root test. We test the null hypothesis of unit root against the alternative. Table 4 shows the results of both tests. At the first difference the null hypothesis is ruled out therefore we conclude that all the variables are integrated of order one I(1) and no variable is integrated of order two. We proceed on to cointegration after determining the variables’ stationarity.

Lag length selection

Table 5 shows the results of several lag selection criteria. The usage of Akaike information criterion (AIC), Schwarz criterion (SC) and Hannan Quinn criterion (HQ) as the most popular methods for determining appropriate lags has been reported in empirical research. For lag selection, SC is used in this study which suggests that lag one is the better option because the lowest result is acquired at lag one.

ARDL bounds testing

Cointegration testing is required after confirming the unit root result and optimal lag selection. To calculate the ARDL model’s long-run coefficient, we must use the bound test to confirm the existence of a long-run link among the variables. The alternative is compared to the null hypothesis of no cointegration. The results of the cointegration test are shown in Table 6. We reject the null hypothesis because the F-statistics is bigger than the upper bound critical values at various significance levels. As a result, our empirical evidence reveals that the variables under discussion are cointegrated.

Diagnostic tests

The study applies a range of diagnostic statistical tests, the results of which are provided in Table 7, to ensure that the model we’ve chosen is accurate. Our model appears to be well fitted, as evidenced by the fact that it passed all diagnostic tests. We check the null proposition of no serial dependence, homoscedasticity, and no functional form mis-specification against the alternative. In all the cases, we fail to reject the null hypothesis. The Breusch Godfrey LM test

| Lag | AIC Equation iv | SC Equation iv | HQ Equation iv | AIC Equation v | SC Equation v | HQ Equation v |
|-----|----------------|----------------|----------------|----------------|----------------|----------------|
| 0   | −5.294         | −4.311         | −6.158         | −8.175         | −7.796         | −7.627         |
| 1   | −18.295        | −19.094*       | −21.382*       | −17.328        | −21.453*       | −18.584        |
| 2   | −18.385        | −18.148        | −20.691        | −22.771*       | −19.831        | −22.734*       |
| 3   | −18.729*       | −14.901        | −17.182        | −21.152        | −20.239        | −19.439        |

* indicates lag order selected by the criterion

| Equation iv | Lower bound | 1% | 5% | 10% | Prob. F stat | Long run relation |
|-------------|-------------|----|----|-----|-------------|-------------------|
|             |             |    |    |     |             |                   |
|             |             | 7.357 | 4.927 | 4.321 | 0.001 | Yes |
|             |             | 7.802 | 5.361 | 4.486 | 0.000*** |
| Equation v  |             | 6.807 | 5.921 | 5.024 | 0.000 | Yes |
|             |             | 7.956 | 6.274 | 5.761 | 0.000*** |

Kripfganz and Schneider (2018) probability values. *** denote significance at 1% level

| Diagnostic tests | χ² P values equation iv | χ² P values equation v | Results |
|------------------|-------------------------|------------------------|---------|
| Breusch Godfrey LM test | 0.3312 | 0.7085 | No problem of serial correlations |
| Breusch-Pagan-Godfrey test | 0.2910 | 0.0959 | No problem of heteroscedasticity |
| Ramsey RESET test | 0.5543 | 0.1557 | Model is specified correctly |
verifies that there is no serial correlation. According to the findings of the Breusch-Pagan-Godfrey test there is no heteroscedasticity. The Ramsey RESET test is employed, and the results show that the model is not misspecified.

**Results of novel dynamic ARDL simulation**

As describes above after testing the order of integration of the variables, we have chosen the optimal lag length for each model. Latter we have applied bounds test to determine the long run relationship between the variables. In the next step, long run and short run results are obtained which are given below in the Table 8.

**Long-run results**

The scale effect is represented by real GDP per capita (Y), while the technique effect is represented by (Y^2). The income effect, when broken down into scale and technique effects, yields various results. The results reveal that the scale effect deteriorates the environment while the technique effect improves it. When production techniques remain constant, an increase in economic growth in the early phases of development degrades the environment. After attaining a certain level of economic growth, the demand for cleaner environmental practices and safe industrial processes increases, and carbon dioxide emissions fall. The EKC hypothesis is supported by our analysis. Because the scale effect is dominant, the net effect of trade openness on CO2 emissions is negative. The findings are relevant to Pakistan since the country’s economy is developing; diverse conventional energy sources are being employed to achieve rapid economic growth with cheap energy resources, which has a negative impact on the atmosphere and degrades the environment. The positive impact becomes negative as a result of structural change and technological improvement, lowering CO2 emissions when the technique effect begins to dominate the scale effect. These findings are in line with Udeagha and Breitenbach’s (2020) work, which emphasizes the existence of the EKC hypothesis in (SADC). In Tunisia, Mahmood et al. (2019) looked at the nonlinear impact of trade on the environment and the EKC hypothesis. The EKC hypothesis was verified at a threshold level of income of around 292.335 billion US dollars. According to Khan et al. (2019), economic growth has a favorable impact on environmental degradation in Pakistan. In the long and short term, Ahmed and Long (2012) explored and proved the EKC theory for Pakistan. Similarly, in six regions, including South Asia, Bibi and Jamil (2021) find evidence for the EKC hypothesis. The EKC hypothesis exists for South Africa, according to Udeagha and Ngepah (2019, 2021a).

The findings, on the other hand, oppose Saboori et al. (2012), who found a U-shaped relationship between economic growth and CO2 emissions in Malaysia, which contradicts the traditional Environmental Kuznets Curve theory.

| Variables | Coefficient | p-value | Variables | Coefficient | p-value |
|-----------|-------------|---------|-----------|-------------|---------|
| Y         | 0.833845*** | 0.0005  | TO        | 0.322030*** | 0.0147  |
| Y^2       | -0.424318***| 0.0000  | TO*RI     | 0.193619*** | 0.0061  |
| K/L       | 0.049868*** | 0.0086  | TO*(RI)^2 | -0.05536**  | 0.0329  |
| TO        | 0.870265*** | 0.0000  | URB       | 0.028242*** | 0.0001  |
| URB       | 0.157074*   | 0.06821 | GOV       | -0.08055*   | 0.1218  |
| GOV       | -0.001584*  | 0.0846  | d(TO)     | 0.129951*   | 0.0681  |
| d(Y)      | 0.027461**  | 0.0629  | d (TO*RI) | 0.045945**  | 0.0435  |
| d(Y^2)    | 0.001607    | 0.5659  | d((TO*(RI))^2) | -0.03449** | 0.0149  |
| d(K/L)    | 0.053870**  | 0.0538  | d(URB)    | 0.002956**  | 0.0372  |
| d(TO)     | 0.184251*   | 0.09213 | d(GOV)    | 0.004776    | 0.5355  |
| d(URB)    | 0.008407**  | 0.0317  | ECT(-1)   | -0.37839*** | 0.0000  |
| d(GOV)    | 0.064076    | 0.1637  | C         | 0.123263    | 0.1055  |
| ECT(-1)   | -0.41053*** | 0.0000  | R-squared | 0.734837    | 0.763478 |
| C         | -1.455901   | 0.0533  | Adj. R^2  | 0.643049    | 0.681606 |
|           |             |         | Prob. F stat | 0.0000      | 0.0000   |
|           |             |         | Simulations | 5000        | 5000     |

***, **, and * show significance at 1%, 5%, and 1% level respectively.
The EKC theory does not hold according to Ozturk and Al-Mulali (2015), Sohag et al. (2015), and Mensah et al. (2018). The capital-labor ratio (K/L) is used as a measure of the composition effect in this study. According to economic theory, the composition impact is directly related to carbon dioxide emissions. A 0.049 percent increase in CO2 emissions is associated with a 1% increase in the capital-labor ratio. Cole (2006) determines that the composition effect exacerbates environmental problems, which supports our findings. Altering the composition of the output by embracing more capital-augmenting techniques enhances emission intensity when the technology impact is taken into account. According to theory, there is a strong link between capital concentration and pollution concentration (Udeagha and Ngepah, 2019, 2021a, b; Lopez and Islam 2007; Shafik and Bandyopadhyay 1992; Lopez and Islam 2007). Ling et al. (2015), Sadat and Alom (2016), and Tsurumi and Managi (2010) all found contradictory results (2010).

Carbon dioxide emissions are directly related to trade openness. In low-income nations like Pakistan, trade openness encourages the development of polluting businesses. The long-term negative environmental impact of openness adds to the resistance to trade liberalization. Meanwhile, the type of items that make up the majority of a country's exports is one of the possible reasons why trade openness is harmful to the environment. Furthermore, energy-intensive industries such as transportation and manufacturing, which are primarily pushed by trade liberalization, pollute the environment. Khan and Ozturk (2021) reaffirm our empirical findings, claiming that developing countries have a greater rate of pollution discharge due to their reliance on polluting industries. Our findings support those of Khan et al. (2019), who contend that trade openness has exacerbated Pakistan’s environmental problems. Udeagha and Ngepah (2019), Udeagha and Ngepah (2021a, b), Udeagha and Breitenbach (2020), and Jun et al. (2020). There are some contrast findings that support the concept that trade is good for the environment to some extent by raising awareness about cleaner technologies (Ahmed and Long 2012; Awan et al. 2018 and Frankel and Rose 2005).

Both urbanization and CO2 emissions have a direct relationship with one another. As the urban population grows, so does the need for urban housing and the conversion of forest areas to urban areas, resulting in increased CO2 emissions. The urban population in Pakistan is growing as a percentage of the total population, and forest land is being turned into housing societies in metropolitan areas. The environmental damage caused by unplanned urbanization is enormous. As the number of migrants increases towards the urban areas all type of land is diverted into housing and commercial land in an implausible way, impeding proper waste management, worsening environmental quality (Bai et al. 2017), and eventually damaging the environment altogether. Furthermore, a pressure on available resources; food, water, energy, building, and transportation, urbanization adds to environmental damage (Baz et al. 2020). Our findings contradict those of McCarney et al. (2005), who found that as urbanization grows, environmental quality improves.

The coefficient of governance indicates that as the quality of governance improves, the emission decreases. Because governance in Pakistan is weak, with a weak regulatory framework, poor law and order, increased corruption, and less political stability, the governance coefficient is not highly significant. According to theory, competent macro-level governance can make a difference by enacting rules that limit environmental damage (Makdissi and Wodon 2006). Environmental quality and suitability are influenced by good governance; as Tamazian and Rao (2010) pointed out, countries with strong institutional qualities are better positioned to implement trade openness mechanisms to safeguard environmental quality. Our findings are consistent with those of Abid (2016). The findings, however, contradict those of Abdouli and Hammami (2017) and Omri et al (2014).

To depict the pollution haven hypothesis, trade openness is combined with relative income. The quadratic interaction term is negative, whereas the linear interaction term is positive. According to economic theory, the sign pattern exists. The findings demonstrate that in a country with a lower per capita income than the rest of the world, more openness will make it dirtier. These findings support the pollution haven hypothesis, which states that changes in a country’s comparative income determine the composition effect. Trade openness boosts a low-income country’s competitive advantage in dirty goods production (due to its lack of environmental protection). Weak environmental policies have added to the consistent rise in CO2 emanations in poor nations. Pakistan, like other developing countries, has a comparative advantage in polluting industries, while developed countries have a comparative advantage in clean products. As a result, developed countries are more likely to use international trade to export pollution to developing countries (Cole 2006; Wagner 2010; McCarney et al. 2005; Feridun Mete 2006; Qureshi 2006).

Short-run results

The word “error correction” refers to the return to equilibrium following a shock. In the first equation, the speed of convergence is 0.41, indicating that the error in the previous period has been reduced by 41% in the current period. Similarly, in the second equation, the speed of convergence is 0.37, indicating that the error from the previous period is corrected by 37% in the current period. In the short run, the scale effect, composition effect, trade openness, and urbanization are all consistent. EKC is a long-term phenomenon that does not hold in the short run. In the short
In the short run, the majority of the variables lose their significance.

**Impulse response plots**

In the dynamic ARDL model, impulse response functions depict and predict the impending value of a regressed variable in reply to a regressor while the other predictor variable remains constant. We predicted the change in CO₂ emissions in response to a 10% positive or negative change in the explanatory variables in this study. The dots reflect the anticipated value, while the deep blue to light blue lines represent the confidence intervals of 75%, 90%, and 95%, respectively. The following is a description of each figure.

The relationship between per capita income (Y) and CO₂ emissions is depicted in Fig. 1. Each ten percent increase or drop in income, in the short run, invariably damages the environment. However, as time passes, the environmental damage caused by an increase in Y becomes more severe. Over the longer term, however, every ten percent drop in Y reduces CO₂ emissions. Figure 2 depicts the relationship between Y square and CO₂ emissions and shows the opposite outcomes. The CO₂ emissions impulsive reaction to positive or negative changes in the capital-labor ratio (K/L) is forecasted in Fig. 3. Short and long-run environmental quality is significantly affected by a 10% rise or decline in capital intensity. Figure 4 depicts how any shift in urbanization, whether favorable or negative, appears to have a major short-term environmental impact. Furthermore, every ten percent growth in urbanization degrades environmental quality over the longer period. Any decrease in urbanization, on the other hand, leads to a reduction in CO₂ emissions over time.

Figure 5 depicts the CO₂ emissions impulse reaction to changes in trade openness, both positive and negative. Both statistics illustrate that a ten percent increase degrades environmental quality while a ten percent drop improves it. Figure 6 depicts the CO₂ impulse response functions in response to a
Fig. 3 The impulse response plot for K/L and CO₂ emission

Fig. 4 The impulse response plot for URB and CO₂ emission

Fig. 5 The impulse response plot for TO and CO₂ emission
10% change in governance. As shown, both in the shorter and longer-term a 10% increase or decrease in governance has no significant impact on environmental quality. Because of Pakistan’s shaky institutions, the trend of CO2 emissions remains nearly steady over long and short periods, regardless of whether governance improves or worsens.

**Frequency domain causality**

So far we have examined the short and long-run relationship between variables of concern through dynamic ARDL methodology. Hence while making policy suggestions causal relationships between variables are also important. For this purpose, we have employed the frequency domain causality to examine the causal relationship between variables over a range of frequencies as common in literature. We compare the null hypothesis of no causality to the alternative hypothesis. The outcomes are given in Table 9.

Table 9 shows that per capita income and CO2 emissions have a bidirectional long-run causal relationship. As a result, it establishes that long-term per capita income and environmental degradation are linked. Ahmed et al. (2019) discovered a similar finding for Malaysia as well Charfeddine and Mrabet (2017) for MENA countries.

This study shows that, while working to reduce environmental degradation, the possibility of a drop in per capita income should also be considered, lest the economy suffers. There is a bidirectional short, medium, and long-run causal relationship between trade openness and CO2 emissions and urbanization. The capital-labor ratio and CO2 emissions have a unidirectional short, medium, and long run causation. These findings, particularly the bidirectional causality, imply that before enacting policies to reduce pollution, consideration should be given to the potential influence on economic growth, trade openness, and urbanization. Indeed, when establishing plans
to address environmental challenges, regulatory bodies should maintain balances across various sectors. Otherwise, economic activities, trade, and urban residents could be harmed. Our findings are consistent with those of Udeagha and Ngepah (2019), Udeagha and Ngepah (2021a, b), Islam et al. (2021), Saboori et al. (2012), and Hassan et al. (2019).

**Conclusion and policy recommendations**

This section gives an overview of the likely effects of trade liberalization on environmental quality. The section summarizes the previous sections, focusing on the study’s objectives and empirical findings. Finally, we make some critical policy recommendations.

The study examines the dynamic association between trade and CO₂ emissions in Pakistan from 1984 to 2019. The first objective is to look at the impact of trade openness on the environment in Pakistan via scale, technique, and composition. The second objective is to look into the pollution haven proposition for Pakistan. Third, encourage policies that will benefit Pakistan’s environmental damage. We employed the Augmented Dickey-Fuller and Phillips-Perron (PP) unit root tests to confirm the level of integration of all variables under consideration after providing descriptive statistics and correlation among them. As a result, empirical evidence from all tests confirmed that the data series are integrated of order one, I(1), and that there is no evidence of any I(2). The optimal lag length was determined using Schwarz criterion (SC). Serial correlations, heteroscedasticity, and functional form misspecification are examined using diagnostic test statistics. The novel dynamic ARDL simulation model has been used in the study which is advocated by Jordan and Philips (2018). It addresses the constraints of previous studies that used the simple ARDL method and not only develops the short and long-term association between the variables but also stimulates, and generates the graphs of the change in the regressors. In order to determine the direction of causality between the variables over time, we have employed Breitung and Candelon’s (2006) frequency domain causality technique for robustness. It determines the causal relationship between the variables at different level of frequencies and therefore is different from Granger causality which determines the causality at a specific point in time. The study also contributes to the empirical literature by adopting Squalli and Wilson’s (2011) new measure of trade openness, it depicts the country’s trade share relative to GDP as well to global trade.

In terms of the first objective, the findings of the novel dynamic ARDL reveal that in the long run, scale effect contributes positively to CO₂ emission while technique impact contributes negatively. Trade results in an enlargement in the production scale, which leads to an increase in CO₂ emissions. As per capita income rises, so does the demand for a cleaner environment and environmentally friendly technology, which is why carbon dioxide emissions fall rapidly as a result of the technique effect. Trade appears to have a net negative effect on the environment as the scale effect appears to dominate over the technique. In the long run, our findings support the standard EKC hypothesis, which argues that environmental quality declines during the early stages of economic expansion, but improves once the optimal level is reached. Because Pakistan’s economy is growing, many conventional energy sources are being used to achieve quick economic expansion with low-cost energy resources, which deteriorate the environment. As people’s income rises, so does their awareness of the environment. The composition deteriorates the environment quality. In the presence of the technique effect, a higher capital intensity increases CO₂ emissions. Increased CO₂ emissions are a result of increased trade openness. As a result of trade, the environment is polluted by the rise of pollution-intensive export sectors in developing countries and Pakistan as well. CO₂ emissions are positively related with urbanization. Increased urbanization has the potential to deplete forest resources, resulting in increased emissions, as well as increased demand for food, shelter, employment, transportation, and other essential services, all of which contribute to additional environmental degradation. In terms of governance, the findings demonstrate that strong governance helps to reduce environmental degradation by establishing and enforcing environmental rules and regulations, but governance is amazingly poor in developing countries as well in Pakistan. EKC does not hold in the short term. In the long run, governance becomes insignificant, whereas other findings remain consistent. The speed of adjustment is shown by the error correction term, which is 41 percent and 37 percent respectively.

In terms of our second objective, the pollution haven hypothesis has been validated in both the short and long run, demonstrating that lax environmental rules and regulations are contributing to the rise in pollution-intensive activities and environmental degradation. These findings imply that opening the country to foreign trade has a significant negative impact on the country’s environmental condition, allowing it to become one of the world’s “havens” for highly polluting enterprises. Pakistan has also become dirtier as a result of its inadequate environmental laws and weak institutions, as the country specializes in producing goods that noticeably degrade the environment.

Results of the frequency domain causality show the bidirectional causality between economic growth and CO₂ emission in the long run. Bidirectional causality exists between trade openness and CO₂ emission and urbanization and CO₂ emission in short, medium, and long term period. Unidirectional causality is found from the
capital-labor ratio to CO₂ emission. No causality is found between governance and CO₂ emission.

**Policy recommendations**

The following policy recommendations are suggested in light of our empirical findings to reduce environmental degradation:

To begin, it is necessary to increase the use of environmentally friendly technologies in daily life, such as low-energy vehicles, apparatuses, and electrical appliances, in order to reduce energy consumption, which is the primary source of carbon emissions. Furthermore, move from non-renewable to renewable energy sources to assure industrial process competence. Second, the government should enact strict regulations that require polluting companies to adopt clean technology and provide incentives for them to invest in R&D and patenting. Third, international cooperation and collaboration with other countries to share technologies are required to improve environmental quality. Finally, the government should draft environmental legislation and include it in the country’s trade agreements to facilitate the transition to a low-carbon economy and greener industries, thereby stimulating the development of cleaner goods.

The study is restricted to time series analysis. In the future, we can widen our analysis by including a cross-country examination. Furthermore, the study could take into account other associated emission indicators such as ecological footprint, nitrogen dioxide, and sodium dioxide, among others. We might further widen our research by considering environmental goods trade.

**Acknowledgements**

The authors thank the anonymous reviewers for their valuable and helpful comments and suggestions that have helped us to revise the paper and prepare the final draft in a better form. Any remained errors are owned to authors.

**Author contribution**

Azra Khan: conceptualization, introduction, results and discussion, original draft, revised draft. Sadia Saifdar: data, methodology, review and editing, revised draft, Haris Nadeem: Literature review, conclusion, original draft.

**Data availability**

The datasets used and/or analyzed during the current study are available from the corresponding author on request.

**Declarations**

**Ethics approval and consent to participate** Not applicable.

**Consent for publication** Not applicable.

**Competing interests** The authors declare no competing interests.

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