Do Public-Private Partnership Investment in Energy and Technological Transfers Improve Environmental Quality To Achieve Sustainable Environment Agenda: Evidence From Pakistan

Hummera SALEEM (hummera_saleem2015@yahoo.com)
National University of Modern Languages
Muhammad Bilal Khan
Kohat University of Science and Technology

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Do Public-Private Partnership Investment in Energy and Technological Transfers Improve Environmental Quality to Achieve Sustainable Environment Agenda: Evidence from Pakistan

Hummera Saleem[1]*, Muhammad Bilal Khan[2]

Abstract

This paper tries to find the relationship among economic growth (GDP), import (IMP), export (EXP), public-private partnership investment (PPPG), and technological changes (TEC) on carbon-based CO_2 emissions under the Environment Kuznets curve (EKC) premises during the period of 1980-2019 for Pakistan. This study employed various unit root tests that have been designed, such as Augmented Dickey and Fuller (ADF), ARDL co-integration tests, FMOLS, and DOLS estimation techniques. The results indicate that all the variables are co-integrated and have a short-run association among them. The results of DOLS and FOMLS indicate that CO_2emissions significantly increase due to increases in economic growth. This study also verified the EKC hypothesis and the findings of the study support the EKC hypothesis for Pakistan. CO_2 emissions are significantly decreased by increases in the share of technological innovation, and consumption-based carbon emissions are increased by the share of the trade and public-private investment in energy. The study results suggested that a reduction in the use of non-renewable energy through public-private investment and the use of renewable energy sources is related to energy efficiency policies. The consumption of non-renewable energy sources is high in Pakistan, as compared to renewable energy sources. Appropriate policy tools have been recommended to researchers and policymakers to minimize the harmful effect of global climate change and warming. Thus, environment quality can be enhanced through effective energy policies, sensible saving energy policies, optimized structural changes in the energy sector through effective government policies.

Keywords: GDP, Public-private partnership investment, Technological change, Environmental degradation

Introduction

Recently, global warming and climate change have represented significant challenges for the world's nations. Environment quality reductions can be observed when economies attempt to achieve rapid economic growth. Rapid economic growth is highly associated with community waste problems, air pollution problems of various forms (such as smoke and noise), unexpected changes in weather conditions, dangers to biodiversity, increased earth temperatures, forest logging, and resource deficiency issues. This unfavourable environmental quality loss can be reduced through sustainable economic growth. Improving environmental care and mitigating CO_2 emissions are the primary concerns of various countries. Thus, the construction of carbon-intensive technology and infrastructure in the public transportation, electricity, sanitation sectors, and water supply are highly

[1]* Corresponding Author, National University of Modern Languages (NUML), Islamabad, Pakistan.
Email: hummera_saleem2015@yahoo.com
[2] Kohat University of Science and Technology (KUST), Kohat, KPK, Pakistan.
Email: bilal_fh786@yahoo.com

associated with greenhouse gas (GHG) emissions. Simultaneously, it is projected that it is essential to construct new or rehabilitate aging infrastructure according to global demand over the coming years. "The Joint Research Center of the European Union (EU)" reported that 90 percent of the world's CO_2 emissions are due to fossil fuel incineration (Oliver et al., 2012). Developed countries have been primarily responsible for environmental degradation in recent decades; however, the ratio of CO_2 emissions has also increased in developing countries (IEA, 2014). Policymakers and researchers are currently focusing on renewable energy sources as alternatives to non-renewable energy sources. The use of renewable energy sources is estimated to increase from 10 percent of total energy sources in 2010 to 14 percent in 2035 globally (EIA, 2012).

Energy sustainability management is now a global concern, and national and local governments have taken a significant interest in meeting the public's needs by addressing energy cost savings objectives, i.e., reducing carbon and sustainable growth. The public budget limitations, both in terms of public expenditure cuts and contractions of public funding, In terms of both the general public budget cuts and the decline of public funds available, and the lack of appropriate and reliable management and technological capabilities in public administration, the most significant challenges are among the different hurdles that the public sector faces in carrying out energy conservation programs (Lee et al., 2003). Alternative municipal procurement models, which gradually use the private sector to execute energy-efficient programs, would be necessary to address these challenges (Roshchanka and Evans, 2016). Receiving the Public-Private Partnerships (PPPG) as a revolutionary method to establish energy-efficient projects, many politicians have recently introduced PPPG as the most crucial factor of environmental quality (Grimsey and Lewis, 2002, Ahmad et al. 2020).

Moreover, many critical factors could strongly affect CO_2 emissions. Thus, most essential variables are viewed, i.e., technological innovation and public-private (partnerships)in energy can significantly reduce CO_2 emissions (Khan et al., 2020c; Shan et al., 2018). Therefore, the public-private collaboration helps to clean the environment via technological changes and renewable energy, which provides the opportunity for production in an environmentally friendly environment using a clean process; thus, it is argued that such technologies can improve the global environment (Wen et al., 2020; and Georgatzi, Stamboulis, & Vetsikas, 2020). A lower energy level can be consumed if the economy uses advanced technologies (Sohag et al., 2015). Furthermore, energy consumption structure can be diverted from non-renewable sources to renewable energy sources with efficient technologies. According to Andreoni and Levinson (1998), the process of decontamination mostly depends on technical effects: more significant investment in innovation contributes positively and mitigates pollution.

When countries raise their income, energy consumption, and environmental pollution rate decrease, the innovation strategy with higher returns to scale facilitates improvements in energy effectiveness. Thus, the energy innovation process can accelerate environmental advancements. Therefore, it is well argued that environmental quality is affected by various human activities; various other factors, including trade openness and financial development, must be incorporated in this empirical analysis. This study contains financial development variables in the analyses and follows the work of (Li et al. 2021, Saleem 2020, Khan and Ozturk 2021, Ali et al. 2017 and Nassani et al. 2017).

Economic growth and energy have significantly increased the CO_2 emissions nexus in Pakistan. Furthermore, the government of Pakistan has attempted to mitigate CO_2emissions through different activities based on emission reduction. Environmental degradation is a primary issue, and noxious hazes can be seen in many Asian countries, including Pakistan. These noxious hazes negatively impact local inhabitants, and people are also bearing the economic cost. Consequently, Asian countries with growing populations, rapid industrialization, and rapidly growing economies significantly increase CO_2 emissions. The Kyoto Protocol agenda stresses developing countries to reduce carbon emissions in efforts to mitigate global warming. The developing countries are considered an excellent study field for scholars who want to support energy efficiency policies and reduction in CO_2 emission globally, as the extensive energy use and CO_2 emitter. This research fills the investigation vacuum in the context of Pakistan from 1980 to 2019 by looking at specific new covariates of carbon reduction–energy nexus. This research explores the impact of energy and technical development of public-private collaborations on CO_2 emissions in Pakistan. While various literature explores different factors influencing CO_2 emissions, the role of public-private partnerships with technological innovation was not examined exclusively with the help of the latest established tools of econometrics in the framework of the Environmental Kuznets Curve.

A comprehensive background of growth-energy-induced emissions with other control variables, i.e., technological innovation, public-private partnership, import, and export, is presented in this analysis. This analysis reveals the main contributors of CO_2 emissions in the context of Pakistan and how these economies are attempting to follow the commitments of international agreements to mitigate the level of CO_2 emissions. Furthermore, the background presented in the introduction indicated that energy-efficient technology and renewable energy alternatives to fossil energy are environment-friendly sources of energy. These are considered important sources of carbon-free energy by environmentalists. The use of renewable energy may reduce the dangers of energy security and climate issues to meet the environmental protection targets by 2050. Similarly, the public-private partnership investment can finance the green acquisition and technological innovations to mitigate CO_2 emissions. When assessing the complex association between energy use, growth, and the CO_2 emission nexus in the previous literature, we found that financial investment and technological innovation are often ignored by various researchers in their equation of the EKC framework model. Therefore, investment (public-private) in green financing and technological change are incorporated as the critical components of CO_2 mitigation to expand the research target. The latest studies of Ahmad et al. (2020), Khan et al. (2020c) on the growth-energy-emission nexus have also not discussed public-private partnership under the scheme of EKC in their analysis. These contributions are crucial; the study seeks to use those essential variables in the EKC framework and is helpful in policy implication for policymakers.

The study contributes different results because of the period, econometric methodologies, and model specifications. Thus, the contribution of this research is unique under the EKC framework with its plausible variables, which makes this study different from other studies and fills a gap in the literature. Pakistan, the public-private partnership, technological change, and trade are not used together (in the framework of the EKC hypothesis) in Pakistan. This research has concluded that the composition and the contributions of technical effects can be determined by the associations in the trade (imports and export) and environmental degradation nexus. According to the study, the process of decontamination mostly depends on technical effects: more significant investment in innovation contributes positively and mitigates pollution. The innovation strategy with higher returns to scale facilitates improvements in energy effectiveness. Thus, the energy innovation process can accelerate environmental advancements.

Consequently, the initial turning point may be reached within the EKC scheme with a lower income obligation. Implementation reforms and technological changes would be essential to this process. Many studies conflict with each other, and their results are not suitable for all countries. Thus, this study tries to analyze it separately and minimize the harmful effect of global climate change and warming; researchers and policymakers have recommended appropriate policy tools. The rest of the paper covers the introduction in the first part; the second part covers literature reviews; the third part covers the methodology and theoretical background; the fourth part covers the interpretation and discussion of results, while the last section covers the conclusion and policy recommendations based on empirical findings.

2. Literature review

The EKC framework is used in this study with the help of time-series data analysis. Then the contribution of the current research cannot be deniable in the existing literature to find out the main component of environmental degradation. Furthermore, the study uses GDP growth, the square of GDP growth, public-private partnership, and ecological protection-related technological change as the main determinants of CO_2 emissions under the EKC premises. Therefore, this literature review focuses on theoretical and empirical points of view. Thus this is subdivided into two sections. The first section discusses the academic background of the energy and the income-environment relationship in the EKC scheme in detail. Secondly, we examine technological innovation and its relationship with environmental degradation, and finally, we have discussed the impact of public-private partnerships on environmental degradation in the context of Pakistan.

2.1 The impact of public-private partnership on environmental degradation

PPPG investment is undoubtedly essential for technological innovation and energy production to mitigate environmental degradation (Shahbaz et al. 2020, Raza et al. 2021). Many researchers, including Inglesi-Lotz (2015), Saleem (2020), and have shown that investments in research and development (R&D) along with technological innovation have significant impacts on GDP growth. Therefore, energy efficiency and a reduction in fossil fuel consumption can be attained through technological innovation. In addition, renewable energy as an alternative to fossil energy use represents a more environmentally friendly energy source and is considered an essential carbon-free energy source by environmentalists (Rehman et al. 2021, Koondhar et al. 2021, and Boroojeni et al., 2016). However, less attention has been given to PPPG investment by many researchers. More attention is warranted to assess the impact of PPPG investment through efficient (technology) energy sources on CO_2 emissions. Efficient technology less energy is used when an economy adopts efficient technology. Sohag et al. (2015) showed that changing the energy structure and adopting renewable energy are highly associated with technological innovation. Thus the significance of PPPG investment cannot be denied mitigating the CO_2 emission. Waqih et al. (2019) found a strong relationship between PPPG investment and CO_2 emission for the SAARC countries over 1986 to 2014 using panel ARDL and FMOLS.

The empirical analyses of Shahbaz et al. (2020) for China over 1984-2018. He has applied the ARDL cointegration test to examine the effects of PPPG investment in energy, indicating that CO_2 emissions-energy nexus and found that PPPG investment is positively related. Álvarez-Herránz et al., (2017) showed that the final and third stage of the EKC scheme shows improvements in production capacity and more high technology and cleaner technologies, and these technical effects will improve environmental quality. They also confirmed the technological innovation-emission nexus hypothesis. They have applied a finite inverted V-lag distribution test for the Organization for Economic Co-operation and Development (OECD) nations to examine the energy innovation(public budget for energy)-emissions nexus from 1984 to 2018. They have highlighted the importance of energy innovation and renewable energy use (with the help of public investment in the energy sector) in improving environmental quality

Khan et al. (2020c) have applied the Maki co-integration test, generalized least square (GLS) and ordinary least square (FMOLS), dynamic ordinary least square (DOLS), test to examine the effects of energy, public-private partnership investment, and innovation on CO_2 emissions for China over the period of 1990Q1-2017Q2. This empirical analysis used CO_2 emissions as dependent variables, and the other variables were the essential determinants of CO_2 emissions. Their results indicate that technological innovation and progressive public-private partnership investment can improve environmental quality, and environmental degradation can be minimized through better environment-growth policies. The study tested the EKC hypothesis and investigated the links among economic growth, energy use, and CO_2 emissions. The results of the study confirm the presence of the EKC hypothesis. The long-term results indicate that CO_2 emissions are inversely related to public-private partnership investment.

Ahmad and Raza (2020) tested this hypothesis for Brazil from 1984 to 2018, including trade and FDI as the main components of CO_2 emission. They also have examined the association between investment of public-private partnerships and air pollutants under the EKC framework and have endorsed the robust inverted EKC association among the variables. Their results support the inverted EKC hypothesis. Their study has also examined the pollution haven hypothesis and has found that higher FDI is associated with significantly higher CO_2 emissions.

2.2 The income-environment relationship in the EKC scheme

Various prior studies have significantly discussed the nexus between income inequalities and growth; in 1995, Kuznets initially developed this inverted U-shaped curve. Later on, numerous researchers in their analysis used this new idea to identify the nexus between income and environment under the structure of the EKC scheme (Grossman and Krueger, 1991; Shafik and Bandyopadhay, 1992; Lucas et al., 1992; Panayotou, 1993; Selden and Song, 1994; and Vincent, 1997). In addition to the relationship between income and environmental impacts, there is a growing body of studies on the link between energy, environment, and income (Bölük G and Mert, 2014, Sarkodie and Ozturk 2020, Brandi et al. 2020; Ibrahim and Ajide 2020; Zhang 2020; Kolcava et al. 2019). Energy is a fundamental input for production and consumption; it is the basis for economic growth (Shaheen et al., 2020). At this stage, focusing on the connection between energy, environment, and income and the basic EKC concept contributes to the current body of literature because carrying out both sides of the analysis provides an opportunity to compare the two branches of the EKC. The EKC hypothesis emphasizes that environmental problems resulting from economic development can be avoided with sufficient economic growth in developed and underdeveloped economies. Thus, discussions about global environmental issues are biased to follow the EKC hypothesis.

2.3 Technological innovation and its relationship with environmental degradation

A significant contribution of technological change (innovation) is found in energy-related growth; this follows the endogenous growth theory, especially for the energy utilization and growth process. Environmental pollution problems can be reduced by innovation externalities (Romer 1990), as technological innovations significantly improve the quality of the environment. This supposition implies that technological improvements follow the environmental correction measures based on increasing returns (in the long-term), which mitigate environmental pollution with an increasing economic growth rate. Many studies discuss the interaction between energy innovation and the correction of environmental quality is significantly discussed within the EKC framework. The production capacity of the economy initially raised the environmental degradation through the depletion of natural resources. But it is essential to achieve sustainable economic growth and welfare through technological innovation to mitigate CO_2 emissions.

Technological innovations based on environmental protection technologies are also essential to mitigate CO2 emissions and to improve energy source efficiency (Chen 2021, Ibrahim and Ajide. 2021 Shahbaz et al. 2020, Chen et al. 2020, Saleem et al. 2020, Usman et al. 2020, Xinmin et al. 2020, Ahmad et al. 2020; Khan et al. 2020b) Fisher-Vanden et al., 2010 and Nan et al., 2010). A lower level of energy can be consumed if the economy uses advanced technologies (Chen 2021). Furthermore, energy consumption structure can be diverted from non-renewable sources to renewable energy sources with efficient technologies. Technological innovation is a crucial component to mitigate CO_2 emission and is vital for diminishing the consumption of non-renewable energy sources (Zhao et al. 2020; Zuo et al. 2020 and Chen and Lei, 2018). Recently, a few studies by Kahouli (2018), Fernández et al. (2018), Kocak, and Ulucak (2019), Inglesi-Lotz (2015); and Sohag et al. (2015) have discussed the associations among technological innovation, energy use, and CO_2 emissions and also consider various regions while examining about the impact of technological change on CO_2 emissions.

Since global warming is becoming more serious, investment in renewable energies and more efficient energy use are needed to minimize the CO_2 emissions. At the same time, the different sectors must be encouraged to adopt advanced technology that minimizes pollution. Furthermore, the use of technological innovation or technology to mitigate the level of CO_2 emission is essential, especially to encourage renewable energy technologies. In order to achieve higher growth levels, the production process could be made free from less efficient and dirty technologies and should be replaced by environmentally friendly technologies. Thus, energy-saving technologies and increased energy efficiency may raise economic growth. These empirical analyses address in the literature, in which technological innovation significantly decreases CO_2 emissions.

Similarly, the financial sector can finance green investment and technological innovations to mitigate CO_2 emissions (Khan and Ozturk 2021, Saleem et al. 2020). When assessing the complex association between energy use, growth, and the CO_2 emission nexus in the previous literature, we found that various researchers often ignore the Public-Private Partnership and technological innovation in the EKC framework model equation. Therefore, Public-Private Partnership investment in green financing and technological change is incorporated as the key components of CO_2 mitigation to expand the research target.

3. Model specification and theoretical foundation

This study tries to examine various determinants of CO_2 under the frame of EKC using evidence from Pakistan from 1980 through 2019. The key research questions are: (1) Is there any association among non-renewable and renewable energy sources, GDP growth, and a public-private partnership with CO2 emissions under the Environmental Kuznets Curve (EKC) framework? And (2) Does OECD countries support the evidence of the EKC hypothesis? So, then how the issues of environmental degradation can be improved through potential policy implications?

3.1 Theoretical framework

The theory of Grossman and Krueger (1991) (well known as EKC) is more attractive and advanced than traditional economic growth theories because it demonstrates the trade-off between economic growth and environmental quality. Grossman and Krueger (1991) extended the initiative of Simon Kuznets (1955) and introduced an inverted U-shaped EKC. Numerous past empirical studies have extensively covered the topic of environmental sustainability and have provided a sustainable framework and various policy implications for environmental protection and sustainable economic growth. The EKC, designed by Kuznets (1955) in a seminal work, reveals the different stages of economic development and their effects on air pollution. The three stages of the EKC show that when an economy moves from a traditional agricultural sector to an industrial sector, environmental degradation is high at the first stage. Finally, the EKC scheme shows that when an economy moves towards the service sector, there are demands for a clean environment. Based on these theoretical aspects, economic growth, energy use, environmental pollution, and several additional variables are used in our analysis within the framework of the EKC method.

A significant contribution of technological change (innovation) is found in energy-related growth; this follows the endogenous growth theory, especially for the energy utilization and growth process. Environmental pollution problems can be reduced by innovation externalities (Romer 1990), as technological innovations significantly improve the quality of the environment. This supposition implies that technological improvements follow the environmental correction measures based on increasing returns (in the long-term), which mitigate environmental pollution with an increasing economic growth rate. The interaction between energy innovation and the correction of environmental quality is significantly discussed within the EKC framework in this study as well.

3.2 Data and methodology

Based on these theoretical aspects, GDP growth, environmental pollution, and several additional variables are used in our analysis within the framework of the EKC method (in equation 1).

The econometric model based on the framework of EKC is given below,

$$CO_{2t} = b_1 + b_2 GDP_t + b_3 (GDP_t)^2 + b_4 Z_t + \mu_{it} \qquad (1)$$

where CO_{2t} shows the carbon emission (per capita) level (to measure the level of environmental pollution), economic growth (per capita) is used as GDP and Z_t shows the plausible determinants of CO_2. Where b_2, b_3, b_4 .....b_7 are the coefficients of GDP and other key variables of CO_2. This study used the different variables with different measuring units, so we have taken the log of all variables for simplicity of analysis.

$$\log CO_{2_t} = b_1 + b_2 \log GDP_t + b_3(\log GDP_t)^2 + + b_4 \log TEC_t + b_5 \log IMP_t + b_6 \log EXP_t + b_7 \log PPPG_t + e_{it} \quad (2)$$

The GDP and quadratic form of GDP growth (per capita) are used in this analysis where equation (2) included variously plausible to examine the influence of GDP growth, import and export, public-private partnership investment, and technological changes on CO_2 emissions in the context of Pakistan over the period of 1980-2019.

Description of data

Table 1 Statistical Summary of data description

Variables	Description	Source
CO_2	Carbon emissions (measured in metric tons per capita)	(WDI)
GDP	GDP per capita (in US$ with the base year of 2010)	(WDI)
TEC	Total number of patent applications	(WDI)
EXP	In terms of % share of total GDP	(WDI)
IMP	In terms of % share of total GDP	(WDI)
PPPG	The Public-Private Partnerships investment in energy is measured in US dollars	(WDI)

The paper tries to analyze the time series data for Pakistan from 1980 through 2019. The CO_2 emission in metric tons per capita (WDI, CD-ROM) is measured to use the environmental degradation. The economic growth is measured as GDP per capita (in US$ with the base year of 2010) (WDI, CD-ROM). The demand for non-renewable sources is higher due to their high availability and low cost, and converting from one energy type to another is also cheap. Rapid industrialization and urbanization require more energy sources. Numerous developed and developing nations are highly dependent on fossil fuel energy sources and significantly contribute to CO_2 emissions.

Furthermore, IMP and EXP variables are measured in the percentage share of total GDP (WDI). The applications of the patent (TEC) both by non-resident and resident are included in the variable. PPPG in energy shows that those energy projects based on financial closure are measured in US dollars (WB, 2019). The World Development Indicator (CD-ROM, 2019) is used to take the data of all variables.

3.3 Methods

3.3.1 Bounds testing approach

The equation of bounds testing analysis is given as below,

$$\Delta \ln CO_{2_t} = \alpha_1 + \alpha_I \ln GDP_{t-i} + \alpha_2 \ln IMP_{t-1} + \alpha_3 \ln TEC_{t-i} + \alpha_4 \ln EXP_{t-i} + \alpha_5 \ln PPPG_{t-i} + \sum_{j=1}^{q} \delta_1 \Delta ln GDP_{t-i} + \sum_{j=1}^{q} \delta_2 \Delta \ln IMP_{t-i} + \sum_{j=1}^{q} \delta_3 \Delta \ln TEC_{t-i} + \sum_{j=1}^{q} \delta_4 \Delta \ln EXP_{t-i} + \sum_{j=1}^{q} \delta_5 \Delta \ln PPPG_{t-i} + \mu_t \quad (4)$$

The intercepts of the model are α_1, β_1 *and* δ_1 and the error term is μ_1 and expected to be white noise. The Akaike Information Criterion (AIC) is used to check the optimal lag length of the given model.

The results of bounds testing analysis found that the variables are co-integrated, and the outcome confirms the association among the variables. Then the long-run and short-run association can be measured through the autoregressive distributive lag (ARDL) approach.

3.3.2 Autoregressive distributed lag (ARDL) model

To find out the co-integration among the variables, the use of ARDL technique in any study, the results of the model can not be spurious even with different orders of integration such as I(1) and I(0) and small sample size (Pesaran et al. (2001). This study also used the ARDL technique where some variables are endogenous and exogenous, which is used with different leg lengths, so variables become unbiased in long-run analysis.

The bounds test estimation's results for ARDL (long-run) equation can be written as below:

$$\ln CO_{2_t} = \alpha_1 + \sum_{l=1}^{m} \sigma_1 \Delta ln GDP_{t-i} + \sum_{l=0}^{m} \sigma_2 \Delta \ln IMP_{t-i} + \sum_{l=0}^{m} \sigma_3 \Delta \ln TEC_{t-i} + \sum_{l=1}^{m} \sigma_4 \Delta \ln EXP_{t-i} + \sum_{l=1}^{m} \sigma_5 \Delta \ln PPPG_{t-i} + \epsilon_t \quad (5)$$

The equation mentioned above shows the σ_1 -σ_5 co-efficents represent the long-run association between the variables. The equation of the error correction model is given as below:

$$\ln CO_{2_t} = \alpha_1 + \sum_{l=1}^{m} \varphi_1 \Delta ln GDP_{t-i} + \sum_{l=0}^{m} \varphi_2 \Delta \ln IMP_{t-i} + \sum_{l=0}^{m} \varphi_3 \Delta \ln TEC_{t-i} + \sum_{l=1}^{m} \varphi_4 \Delta \ln EXP_{t-i} + \sum_{l=1}^{m} \varphi_5 \Delta \ln PPPG_{t-i} + \lambda ECT_{t-i} + \epsilon_t \quad (6)$$

The equation mentioned above shows the φ_1 -φ_5 co-efficient, illustrate the short-run association between the variables. The error correction model determines the speed of adjustment, which shows how the model can be reached at equilibrium position from short-run to the long-run equilibrium position.

3.3.3. FMOLS and DOLS tests

Environmental degradation significantly decreased with the use of technological advancement. However, it increased with the help of public-private investment in energy and economic growth, based on using dynamic ordinary least square (DOLS) and FMOLS methods for Pakistan from 1980 through 2018 to evaluate the EKC hypothesis. Phillips and Hansen (1990) have designed the FMOLS, and

Saikkonen (1992) proposed the method of DOLS. Long-term relationships can be found between these selected independent variables and dependent variables.

4. Empirical results and discussions

The results of descriptive statistics show the leading statistics and features of the data analysis of the model. Table (2) reported the descriptive statistics of all independent and dependent variables.

Table (2): The results of descriptive statistics

	LCO2	LIMP	LTEC	LPPPG	LEXP	LGDP
Mean	1.9394	1.2795	2.8610	7.6479	1.1188	11.0576
Median	1.9820	1.2950	2.8309	7.2695	1.1279	11.0582
Maximum	2.2973	1.3674	3.2166	9.1840	1.2373	11.4094
Minimum	1.4443	1.1220	2.5670	7.2552	0.9168	10.6348
Std. Dev.	0.2503	0.0650	0.1868	0.6122	0.0795	0.2216
Skewness	-0.4451	-1.0183	0.0843	1.1986	-0.6347	-0.1894
Kurtosis	2.0600	3.34542	1.9352	2.8752	2.9393	1.9818
Jarque-Bera	20.7935	1 7.1129	19.9367	16.2431	28.6921	14.9669
Probability	0.2473	0.0285	0.3797	0.0440	0.2602	0.3740
Sum	77.5782	51.1815	114.4423	198.8464	44.7546	442.3023
Sum Sq. Dev.	52.4439	45.1648	18.3616	19.3721	2 0.2466	11.9166

Before testing the cointegration method, the stationary testing technique is essential to identify the statistical properties of the model. The results of time series unit root analysis reveal non-stationary characteristics of the incorporated variables. The stationary testing technique is essential to identify the statistical properties of the model. To determine the long-run association between the dependent and independent variables, highlighting the unit root issue cannot be denied. Thus, for this purpose, various unit root tests have been designed Augmented Dickey and Fuller (ADF); Philips Perron (PP). The unit root test is a prerequisite in time series econometrics analysis (Ozturk and Acaravci, 2013). This study employed these two unit root tests to identify whether time series data have the issue of a unit root. The order of integration (I(0) and I(1)) found not the same in the table (3); thus, we are in a position to use the ARDL approach.

Table (3): The results of unit root tests

Variables	**Constant and trend**	**Constant and Trend**
	ADF(At level)	**PP test (At level)**
CO_2	0.8848	2.6126
GDP	−0.1438	−2.5802
IMP	−2.7502	−2.7466
EXP	−2.0812	−2.7751
TEC	−2.7078	−2.7078
PPPG	−2.1045	−2.1045
	ADF(At first difference)	**PP test (At first difference)**
CO_2	−8.5735***	−8.9226***

GDP	−5.6223**	−8.2356***
IMP	−7.9915***	−8.9853***
EXP	−5.8906**	−4.1254**
TEC	−6.8760***	−7.3019***
PPPG	−8.9828***	−13.9876***

Notes: The ** and * indicate significance at 1 % and 5 % levels of significance, respectively. The table represents the test of ADF and PP (unit root test).

Additionally, before adopting the co-integration technique with ARDL bounds analysis, F statistics are calculated with the proper leg length selection criteria (Raza and Shah 2019; Satti et al. 2014; Shahbaz and Lean 2012). The outcomes of F statistics are represented in table (4). The result indicates that the value of F statistics is not beyond the upper and lower value of bound test analysis at a 5 % level of significance. Thus, the result shows a long-run (co-integration) relationship found among all selected variables.

Table (4): ARDL Bounds testing to co-integration analysis

Bounds testing to co-integration		
Estimated model	$\log CO_{2_t} = f(\log GDP_t, (\log GDP_t)^2, \log NRENW_t, \log TEC_t, \log IMP_t, \log EXP_t, \log PPPG_t)$	
Optimal lag length (p)	(1,10,11,0,1)	
F statistics (Wald test)	6.09	
	Lower bounds I(0)	Upper bounds I(1)
1 % level of significance	4.74	5.10
5 % level of significance	2.45	4.67
10 % level of significance	2.25	3.25
Diagnostic tests	χ^2 (p value)	Conclusion based on p-value
Jarque-Bera (J-B) normality test	1.01(0.63)	Normality found in residuals of the data
Breusch–Godfrey LM test (for serial correlation)	2.19(0.33)	Serial correlation is not found in the data
ARCH test	0.20(0.68)	Data found no issue of heteroskedasticity
Ramsey reset test	t=0.66(0.52)	Model is correctly specified
CUSUM test	Stability found	Model is stable
CUSUM square	Stability found	Model is stable

Notes: The Akaike Information Criterion (AIC) optimal lag selection criteria are used in this study.

The *** and ** show the level of significant at 1 and 5 %, respectively.
After using the ARDL approach, we used the Wald test to find the value of F- statistics. The results also indicate (in table 5) long-run relationships among the GDP growth, import and export, public-private partnership investment, and technological changes on CO_2 emissions. Table (5) represents the results of

long-run estimation where the ARDL test examines the effects of energy and GDP growth on CO_2emissions for Pakistan. The long-term relationships between these selected variables are significantly associated with CO_2emissions in the co-integration analysis. The results indicate that all the variables are co-integrated, and there is a long-term association. The results also support the EKC hypothesis, and public-private investment, GDP growth, import, and export significantly worsen environmental quality.

Table (5): Long-run ARDL estimations

Variables	Coefficient	t –statistics
GDP	0.8939	19.7326***
GDP_t^2	-0.1129	-3.8780***
IMP	0.1845	3.6761***
EXP	0.4405	4.4548***
TEC	-0.1173	-5.1535***
PPPG	0.1067	2.3187***
Diagnostic tests	χ^2 (p value)	Conclusion based on p-value
R^2	0.788	
Jarque-Bera (J-B) normality test	1.01(0.63)	Normality found in residuals of the data
Breusch–Godfrey LM test (for serial correlation)	2.19(0.33)	Serial correlation is not found in the data
ARCH test	0.20(0.68)	Data found no issue of heteroskedasticity
Ramsey reset test	t=0.66(0.52)	Model is correctly specified

Notes: *** indicates the significant at 1 % levels of significance.

Their results indicate that public-private investment in energy (PPPG) significantly increases CO_2 emissions if other factors remain constant; a 1 percent increase in PPPG would lead to CO_2 increases of 0.11 percent. These results are consistent with Shahbaz et al. (2020). As this study verified the EKC hypothesis: CO_2emissions are significantly decreased by increases technological innovation. The empirical findings of Lantz and Feng (2006), Tang and Tan (2013); Fei et al. (2014); Saleem et al. 2019: and Shahbaz et al. (2020) are consistent with our findings. The CO_2 emissions and per capita income (economic growth) relationship fully supported the inverted U-shaped EKC in Pakistan (where GDP square inversely and GDP is positively related to CO_2 emissions). As economic growth increases due to free trade and fossil fuel energy use (imported goods) lead to CO_2emissions, a 1 percent increase in GDP and GDP square would lead to CO_2 increases of 0.89 and -0.11 percent, respectively. The results are consistent with the findings of Shahbaz et al. (2012); Can and Gozgor (2017); Lin and Raza (2019), Saleem et al. (2020), Ahmad et al. (2020), khan et al. (2020 a,c) and Shahbaz et al. (2020). CO_2emissions are decreased when an industrial sector converts to a service sector, and when technological change occurs under free trade, CO_2 emissions significantly decline. The developing countries are producing resource-intensive and export pollution-intensive goods. Stern et al. (1996) have observed that free trade increases CO_2emissions, especially in developing countries. Although the results indicate that import and export significantly increase CO_2 emissions, if other factors remain constant, a 1 percent increase in import and export would lead to CO_2 increases of 0.18 and 0.44 percent, respectively. In Pakistan, environmental quality is weaker because open trade and environmental protection standards are also not strengthened compared to rival countries. The results also show that technological innovation significantly improving environmental quality. If other factors remain constant, a 1 percent increase in technological innovation will lead to CO_2 increases of 0.11 percent. The results are endorsed by Lantz and Feng (2006), Tang and Tan (2013); Fei et al. (2014); Saleem et al. 2020: and Shahbaz et al. (2020).

Table (6): Short-run analysis of ARDL estimations

Variables	Coefficient	t –statistics
ΔGDP	1.0731	4.4263***
ΔGDP_t^2	-0.0669	-7.3903***
ΔIMP	0.1092	3.8715***
ΔEXP	0.1602	5.2562***
ΔTEC	-0.0198	-0.8994
ΔPPPG	0.086509	1.8719*
ECT(-1)	-0.5919	-4.6680***

Notes: *** and * indicates the significant at 1 % and 10 % levels of significance, respectively.

Table (6) represents the outcomes of short-run estimation; we have used time-series data with ARDL and the Error-Correction Model (ECM) and examined the income and public-private consumption in energy-driven emissions for Pakistan. The results indicate that all the variables are co-integrated, and there is also a short-run association among the variables. The results also support the EKC hypothesis for Pakistan. Environmental degradation significantly increased with the increase in PPPG, IMP, EXP, and GDP. The speed of adjustment was found significant at a 1 % level of significance according to the value of ECT(-1), where results indicate that it requires 59.1% modification to move (in the short run from the long run) towards the equilibrium position of the analysis.

Table (7): The statistical results of FMOLS and DOLS Models

Dependent variable= CO_2					
FMOLS			DOLS		
Variables	Coefficient	t –statistics	**Variables**	coefficient	t –statistics
GDP	-0.51446	-13.3611***	GDP	-0.2712	3.8910***
GDP^2	0.0626	19.6962***	GDP^2	0.0626	4.7890***
IMP	0.0680	2.1657**	IMP	0.7188	3.3657***
EXP	0.1814	3.6594***	EXP	0.8285	2.6886
TEC	0.1052	4.1901***	TEC	-0.1130	-2.1306
PPPG	0.0131	2.9753***	PPPG	0.0196	0.6822

This study used FMOLS and DOLS estimation techniques for Pakistan to evaluate the GDP, PPPG effects, and other incorporated variables on CO_2 emission under the framework of the EKC hypothesis. The findings support the EKC hypothesis. Table (7) showed that CO_2 emissions are significantly increased using Public-Private Investment in energy, trade, and GDP. If other factors remain constant, a 1 percent increase in GDP growth will lead to CO_2 increases of 0.51 and 0.27 percent for FMOLS and DOLS. These findings are endorsed by Khan et al. (2020c), Ahmad and Raza (2020), and

Liddle (2018), they concluded that CO_2emissions (consumption-based) are significantly increasing due to the increase in GDP.

Additionally, this study found that economic growth is increasing due to increased trade (import and export), leading to environmental degradation. Furthermore, the arguments of proponents of international trade have been well discussed in the existing literature; however, various environmentalists have argued that trade liberalization significantly increases environmental degradation; this is related to the arguments of the pollution heaven hypotheses (PHH). Grossman and Krueger (1991) and Managi et al. (2008) have discussed how many developed countries transfer these dirty products to developing countries because of soft environmental protection policies and regulations. On the other hand, the environmental quality can be improved through technological innovation and environment-friendly innovation in developing countries as technological change may significantly improve energy efficiency and decrease non-renewable energy consumption. Thus, if other factors remain constant, a 1 percent increase in technological innovation would lead to CO_2 increases of 0.10 and 0.11 percent, respectively, for FMOLS and DOLS. The statistical findings of FMOLS and DOLS are consistent with the (Khan et al. 2020c, Kahouli 2018 and Kocak and Ulucak 2019).

The robustness of the model we used structural constancy method, i.e., cumulative sum (CUSUM) and cumulative sum of squares (CUSUMSQ), was established by Pesaran and Pesaran (1997). Figure 1 and 2 illustrates the graphical representation of these two tests. The results of CUSUM and CUSUMSQ indicate that during the selected period, the framework of the model of this study is within limits. These results show that in the long-run analysis, our model is stable.

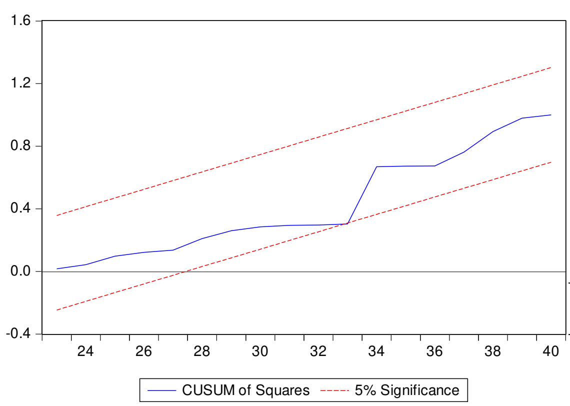

Figure 2: CUSUM of squares test

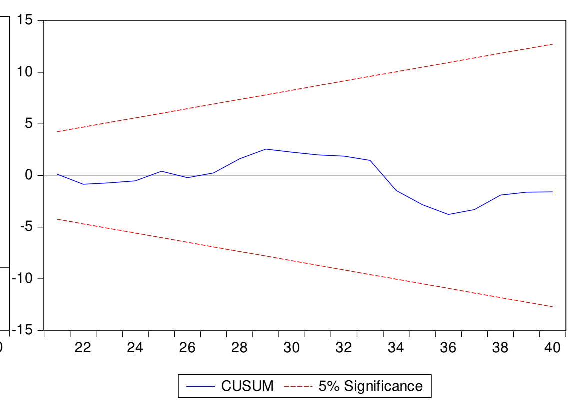

Figure 1: CUSUM Test

5. Conclusion and policy suggestions

Improving environmental quality and mitigating the level of CO_2 emissions are the main concerns of various countries of the world. When evaluating the energy and growth-induced carbon emissions nexus in recent years, there is a strong desire to make a well-balanced economic growth model that provides a better solution for policymakers in the form of sustainable economic growth and improves the quality of the environment. A well-balanced environmental model is used in this study that included public-private investment in energy, GDP, technological innovations, imports, and export as the most significant variables to represent the global agenda of sustainable growth. This study tries to fill that gap in the literature by applying the most recent panel data from 1980 to 2019 for Pakistan. This study used various econometrics techniques, i.e., the ARDL (short-run- long-run) and DOLS and FOMLS techniques.

Additionally, the study uses GDP growth, the square of GDP growth, public-private investment in energy, environmental protection-related technological change, and trade (import and export) as the main determinants of CO_2 emissions under the EKC premises. Improving environmental quality and mitigating CO2 emissions are the main concerns of various countries in this region; however, government agencies have recently made efforts to mitigate CO_2 emissions. Technological innovation (the most significant variable to support the global agenda of sustainable growth) significantly reduces CO_2 emissions. The results of co-integration also reveal a long-term association among these variables. The results of DOLS and FOMLS indicate that CO_2emissions significantly increase due to increases in economic growth. The study also verified the EKC hypothesis. The study's findings support the EKC hypothesis for Pakistan: CO_2emissions are significantly decreased by increases in the share of technological innovation, and consumption-based carbon emissions are increased by the share of the trade and public-private investment in energy. Thus, the results also indicate that environmental degradation is significantly growing, owing to the GDP growth and greater use of energy and importing of oil. Goods being transferred from exporters to importers directly affect CO_2emissions, a phenomenon called direct measures/effects. The service sector contributes less to environmental degradation in developed countries, whereas developing countries produce resource-intensive and export pollution-intensive goods. Stern et al. (1996) have observed that free trade increases CO_2emissions, especially in developing countries. So, we have concluded that it is necessary to increase the use of renewable energy and the contribution of trade services for a low carbon economy.

The study results suggested that a reduction in the use of non-renewable energy through public-private investment and the use of renewable energy sources is related to energy efficiency policies. The consumption of non-renewable energy sources is high in Pakistan, as compared to renewable energy sources. Thus, for this purpose, researchers and research institutions may be supported financially to enhance the efficiency of energy usage and the development of energy conversion technologies and clean energy technologies or renewable energy (i.e., solar, hydropower, geothermal, etc.). Production processes may include renewable energy use that can increase economic growth and mitigate CO_2 emissions levels. Protection and encouragement of renewable energy investments can be made possible by controlling the prices of non-renewable energy sources (especially oil, coal, and natural gas) and increasing taxes for non-renewable sources.

Consequently, improvement of the energy sector can be made possible if energy regulation policies are attached to the application of financial regulations. Environmental quality can enhance financial development if public-private investment in energy is utilized efficiently for energy-efficient firms. The use of renewable energy sources significantly decreases environmental degradation, and the inverse association between renewable energy use and CO_2 emissions has encouraged policymakers to promote renewable energy sources. The technological improvements can be made in the energy sector, and the budget can be allocated for green growth, and energy sources (renewable) can be optimized as key government priorities. The adoption of green technologies and renewable energy in Pakistan can be provided benefits from trade openness.

Economic growth increases due to free trade and fossil fuel energy use lead to CO_2emissions. CO_2emissionsare decreased when an industrial sector converts to a service sector, and when technological change occurs under free trade, CO_2 emissions significantly decline. The service sector contributes less to environmental degradation in developed countries, whereas developing countries produce resource-intensive and export pollution-intensive goods. Thus, environmental quality can be improved through technological innovation and environment-friendly innovation in developing countries like Pakistan. Appropriate policy tools have been recommended to researchers and policymakers to minimize the harmful effect of global climate change and warming. These include renewable energy sources, environmental taxation, and technological change in developing economies. Government policies strongly influence the transitional economic growth phase; these may range from extensive to intensive economic growth policies. Thus, environment quality can be enhanced through effective energy policies, sensible saving energy policies, optimized structural changes in the energy sector through effective government policies. Changes in industrial structure and clean environmental technologies are a prerequisite in Pakistan and significantly reduce CO_2 emissions.

Author Information

National University of Modern Languages (NUML), Islamabad, Pakistan
Hummera Saleem (PhD)
Kohat University of Science and Technology (KUST), Kohat, KPK, Pakistan
Muhammad Bilal Khan (PhD)

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References

Ahmad, M., Raza, M.Y. (2020). Role of public-private partnerships investment in energy and technological innovations in driving climate change: evidence from Brazil. *Environ Sci Pollut Res* 27, 30638–30648

Ahmad M, Khattak SI, Khan A, Rahman ZU (2020) Innovation, foreign direct investment (FDI), and the energy–pollution–growth nexus in Environ Sci Pollut Res Content courtesy of Springer Nature, terms of use apply. Rights reserved. OECD region: A simultaneous equation modeling approach. Environ Ecol Stat:27, 1–30

Ajide KB, Ibrahim RL (2021) Threshold effects of capital investments on carbon emissions in G20 economies. Environ Sci Pollut Res:1–19

Alvarez-Herranz A, Balsalobre-Lorente D, Shahbaz M, Cantos JM (2017) Energy innovation and renewable energy consumption in the correction of air pollution levels. Energy Policy 105:386–397.

Andreoni, J., Levinson, A. (1998). The Simple Analytics of the Environmental Kuznets Curve.NBER Working Paper series No. 6739.

Ali, G., Ashraf, A., Bashir, M.K., Cui, S. (2017). Exploring Environmental Kuznets Curve (EKC) in relation to green revolution: a case study of Pakistan. *Environmental Science and Policy*, 77, 166–171.

Bolük, G., Mert, M., (2014). Fossil & renewable energy consumption, GHGs (greenhouse gases) and economic growth: evidence from a panel of EU (European Union) countries. *Energy* 74, 439-446.

Boroojeni, K.G. Amini, M.H. Nejadpak, A. Iyengar, S.S. Hoseinzadeh, B. Bak, C.L. (2016). A theoretical bilevel control scheme for power networks with large scale penetration of distributed renewable resources, in: IEEE International Conference on Electro Information Technology, pp. 0510-0515.

Brandi C, Schwab J, Berger A, Morin JF (2020) Do environmental provisions in trade agreements make exports from developing countries greener? World Dev 129:104899

Chen W, Lei Y (2018) The impacts of renewable energy and technological innovations on environment-energy-growth nexus: new evidence from a panel quantile regression. Renewable Energy 123:1–

Chen, F., Zhao, T. & Liao, Z (2020). The impact of technology-environmental innovation on CO2 emissions in China's transportation sector. Environ Sci Pollut Res 27, 29485–29501

Chen, L. Environmental cost of sustainable development and climate change: can SAARC shift some liability with renewable energy and efficiency?. Environmental Science and Pollution Research (2021).

Can M, Gozgor G (2017). The impact of economic complexity on carbon emissions: evidence from France. Environmental Science and Pollution Research 24:16364–16370.

Energy Information Administration, EIA (2012). ww.eia.gov/today in energy/detail.cfm?id¼14011 accessed on 07/09/2018.

Fisher-Vanden, K., Ho, M.S. (2010). Technology, development and the environment. Journal of Environmental Economics and Management, 59, 94-108.

Fernández YF, López MF, Blanco BO (2018) Innovation for sustainability: the impact of R&D spending on CO2 emissions. J Clean Prod 172:3459–3467.

Fang, Y. (2011). Economic welfare impacts from renewable energy consumption: the China experience. Renewable and Sustainable Energy Reviews, 15(9), 5120-5128.

Fei Q, Rasiah R, Shen LJ (2014) The clean energy-growth nexus with CO2 emissions and technological innovations in Norway and New Zealand. Energy Environment-Uk 25:1323–1344.

Fei Q, Rasiah R, Shen LJ (2014) The clean energy-growth nexus with CO2 emissions and technological innovations in Norway and New Zealand. Energy Environ-Uk 25:1323–1344. https://doi.org/10.1260/0958-305X.25.8.1323

Georgatzi, V. V., Stamboulis, Y., & Vetsikas, A. (2020). Examining the determinants of CO2 emissions caused by the transport sector: Empirical evidence from 12 European countries. Economic Analysis and Policy, 65,11–20.

Grimsey, D., Lewis, M.K., 2002. Evaluating the risks of public-private partnerships for infrastructure projects. Int. J. Proj. Manag. 20 (2), 107e118.

Grossman, GM., Krueger AB. (1991). Environmental impacts of a North American free-trade agreement. National bureau of economics research working paper, No 3194, NBER, Cambridge. vol. 57.

IEA (International Energy Agency) (2014). International Energy Agency. CO Emissions from Fuel Combustion: Highlights.http://www.iea.org/publications/freepublications/publication/CO2EmissionsFromFuelCombustionHighlights2014.pdf.

Inglesi-Lotz, R., & Dogan, E. (2018). The role of renewable versus non-renewable energy to the level of CO2 emissions a panel analysis of sub-Saharan Africa's Big 10 electricity generators. Renewable Energy, 123,36–43.

Ibrahim RL, Ajide KB (2020) Trade facilitation, institutional quality, and sustainable environment: renewed evidence from Sub-Saharan African countries. J Afr Bus:1–23

Ibrahim, R.L., Ajide, K.B. (2021) Disaggregated environmental impacts of non-renewable energy and trade openness in selected G-20 countries: the conditioning role of technological innovation. Environ Sci Pollut Res https://doi.org/10.1007/s11356-021-15322-2

Khan, M and Ozturk, I (2021). Examining the direct and indirect effects of financial development on CO2 emissions for 88 developing countries. Journal of Environmental Management 293:112812.

Khan Z, Ali S, Umar M, Kirikkaleli D, Jiao Z (2020a) consumption based carbon emissions and international trade in G7 countries: The role of environmental innovation and renewable energy. Sci Total Environ:138945.

Khan ZU, Ahmad M, Khan A (2020b) On the remittances environment led hypothesis: Empirical evidence from BRICS economies. Environ Sci Pollut Res:1–2

Khan,Z Ali, M., Kirikkaleli,D., Wahab.,S., Jiao.Z (2020c). The impact of technological innovation and public-private partnership investment on sustainable environment in China: Consumption-based carbon emissions analysis. Sustainable Development. 2020;1–14.

Kirikkaleli, D.; Adebayo, T.S (2021). Do public-private partnerships in energy and renewable energy consumption matter for consumption-based carbon dioxide emissions in India? Environ. Sci. Pollut. Res. 2021, 1–14.

Kolcava D, Nguyen Q, Bernauer T (2019) Does trade liberalization lead to environmental burden-shifting in the global economy? Ecol Econ 163:98–112

Koondhar, M.A., Shahbaz, M., Ozturk, I. et al.(2021) Revisiting the relationship between carbon emission, renewable energy consumption, forestry, and agricultural financial development for China. Environ Sci Pollut Res 28, 45459–45473

Koçak E, Ulucak ZS (2019) The effect of energy R&D expenditures on CO 2 emission reduction: estimation of the STIRPAT model for OECD countries. Environ Sci Pollut R 26:14328–14338.

Koçak E, Ulucak ZS (2019) The effect of energy R&D expenditures on CO 2 emission reduction: estimation of the STIRPAT model for OECD countries. Environ Sci Pollut R 26:14328–14338

Kahouli B (2018) The causality link between energy electricity consumption, CO2 emissions, R&D stocks, and economic growth in Mediterranean countries (MCs). Energy 145:388–399.

Kuznets S. (1955) Economic growth and income inequality. American Economic Review, 45(1):1–28.

Kahouli B (2018) The causality link between energy electricity consumption, CO2 emissions, R&D stocks, and economic growth in Mediterranean countries (MCs). Energy 145:388–399.

Lee, J., & Strazicich, M. C. (2003). Minimum Lagrange multiplier unit root test with two structural breaks. Review of Economics and Statistics, 85 (4), 1082–1089

Lucas, REB., Wheeler, D., Hettige, H. (1992). Economic development, environmental regulation and the international migration of toxic industrial pollution: 1960–1988. In: Low P, editor. International Trade and the Environment, World Bank Discussion Paper No. 159, Washington DC;

Liddle, B. (2018). Consumption-based accounting and the trade-carbon emissions nexus. Energy Economics, 69(C), 71–78.

Lin B, Raza MY (2019) Analysis of energy-related CO2 emissions in Pakistan. J Clean Prod 219:981–993. https://doi.org/10.1016/j.jclepro.2019.02.112

Lantz V, Feng Q (2006) Assessing income, population, and technology impacts on CO2 emissions in Canada: where's the EKC? Ecol Econ 57:229–238. https://doi.org/10.1016/j.ecolecon.2005.04.006

Managi S, Hibiki A, Tsurumi T. (2008). Does trade liberalization reduce pollution emissions. Discuss Pap:8013.

Nan, Z. Levine, M.D. Price, L. (2010). Overview of current energy-efficiency policies in China, Energy Policy 38 (11) 6439-6452.

Nassani, A.A., Aldakhil, A.M., Abro, M.M.Q., Zaman, K. (2017). Environmental Kuznets curve among BRICS countries: Spot lightening finance, transport, energy and growth factors. Journal of Cleaner Production, 154, 474-487.

Oliver, J.G.J., Jansens, G., Peters, J.A.H.W. (2012). Trends in Global CO2 Emissions 2012 Report. JRC Background Studies. Retrieved from <edgar.jrc.ec.europa.eu/CO2REPORT2012.pdf>.

Ozturk, I., Acaravci, A. (2013). The long-run and causal analysis of energy, growth, openness and financial development on carbon emissions in Turkey. Energy Economics. 36, 262-267.

Panayotou, T. (1993).Empirical tests and policy analysis of environmental degradation at different stages of economic development.World Employment Programme Research, Working Paper WEP 2-22/WP238. International Labor Office, Geneva.

Pesaran MH, Pesaran B (1997) Working with Microfit 4.0: interactive econometric analysis; [Windows version], vol 273. Oxford University Press, pp 239–248

Pesaran MH, Shin Y, Smith RJ (2001) Bounds testing approaches to the analysis of level relationships. J Appl Econ 16:289–326. https://doi.org/10.1002/jae.616

Phillips, P. C., & Hansen, B. E. (1990). Statistical inference in instrumental variables regression with I (1) processes. The Review of Economic Studies, 57(1), 99–125.

Raza, S.A., Shah, S.H. & Yousufi, S.Q (2021). The impact of public-private partnerships Investment in Energy on carbon emissions: evidence from nonparametric causality-in-quantiles. Environ Sci Pollut Res 28, 23182–23192 (2021).

Rehman, A., Ma, H., Ahmad, M. et al (2021). Estimating the connection of information technology, foreign direct investment, trade, renewable energy and economic progress in Pakistan: evidence from ARDL approach and cointegrating regression analysis. Environ Sci Pollut Res 28, 50623–50635 (2021).

Romer, P.M., (1990).Endogenous technological change.Journal of Political Economy 98 (5), 71–102.

Roshchanka, V., Evans, M., (2016). Scaling up the energy service company business: market status and company feedback in the Russian Federation. J. Clean. Prod.112, 3905e3914.

Raza MY, Shah MTS (2019). Analysis of coal-related energy consumption in Pakistan: an alternative energy resource to fuel economic development. Environ Dev Sustain:1–22. https://doi.org/10.1007/s10668-019-00468-4

Saleem, H., Khan, M.B., & Shabbir, M.S. (2020). The role of financial development, energy demand, and technological change in environmental sustainability agenda: evidence from selected Asian countries. Environmental Science and Pollution Research 27 (5), 5266-5280.

Sarkodie SA, Ozturk I (2020). Investigating the environmental Kuznets curve hypothesis in Kenya: a multivariate analysis. Renew Sust Energ Rev 117:109481

Shahbaz M, Lean HH (2012) Does financial development increase energy consumption? The role of industrialization and urbanization in Tunisia. Energy Policy 40:473–479.

Shahbaz M, Raghutla C, Song M, Zameer H, Jiao Z (2020) Public-private partnerships investment in energy as new determinant of CO2 emissions: the role of technological innovations in China. Energy Econ: 104664.

Shan, Y., Guan, D., Zheng, H., Ou, J., Li, Y., Meng, J., … Zhang, Q. (2018). China CO 2 emission accounts 1997–2015. Scientific Data, 5, 170201.

Stern, D.I., Common, M.S., Barbier, E.B. (1996). Economic growth and environmental degradation: the environmental Kuznets curve and sustainable development. World Development 24(7):1151–60.

Satti SL, Hassan MS, Mahmood H, Shahbaz M (2014) Coal consumption: an alternate energy resource to fuel economic growth in Pakistan. Econ Model 36:282–287. https://doi.org/10.1016/j. econmod.2013.09.046

Sohag K, Begum RA, Abdullah SMS, Jaafar M (2015) Dynamics of energy use, technological innovations, economic growth and trade openness in Malaysia. Energy 90:1497–1507. https://doi.org/10.1016/j.energy.2015.06.101

Shafik N, Bandyopadhyay S. (1992). Economic growth and environmental quality: time series and cross-country evidence. Washington, DC: The World Bank;

Selden, TM., Song, D. (1994). Environmental quality and development: is there a Kuznets curve for air pollution emissions?.Journal of Environmental Economics and Management 27: 147–62.

Saikkonen, P. (1992). Estimation and testing of cointegrated systems by an autoregressive approximation. Econometric Theory, 8(1), 1–27.

Tang CF, Tan EC (2013) Exploring the nexus of electricity consumption, economic growth, energy prices and technology innovation in Malaysia. App Energ 104:297–305.

Usman A, Ullah S, Ozturk I, Chishti MZ, Zafar SM (2020) Analysis of asymmetries in the nexus among clean energy and environmental quality in Pakistan. Environ Sci Pollut Res 27(17):20736–20747

Vincent J. (1997). Testing for environmental Kuznets curves within developing countries. Environment and Development Economics,2:417–31.

Waqih MAU, Bhutto NA, Ghumro NH, Kumar S, Salam MA (2019) Rising environmental degradation and impact of foreign direct investment: An empirical evidence from SAARC region. J Environ Manag 243:472–480

Wen, Q., Chen, Y., Hong, J., Chen, Y., Ni, D., & Shen, Q. (2020). Spillover effect of technological innovation on CO2 emissions in China's construction industry. Building and Environment, 171, 106653.

World Development Report, (IBRD, 1992). Development and the Environment. New York: Oxford University Press; 1992.

Xinmin W, Hui P, Hafeez M, Aziz B, Akbar MW, Mirza MA (2020) The nexus of environmental degradation and technology innovation and adoption: an experience from dragon. Air Qual Atmos Health 13(9): 1119–1126 Yang G, Sun T, W

Hafeez M, Maqbool A, Ullah S, Sohail S (2021) Analysis of income inequality and environmental pollution in BRICS using fresh asymmetric approach. Environ Sci Pollut Res:1–11

Zhang J (2020) International production fragmentation, trade in intermediate goods and environment. Econ Model 87:1–7

Zhao X, Gu B, Gao F, Chen S (2020) Matching model of energy supply and demand of the integrated energy system in coastal areas. J Coast Res 103(sp1):983. https://doi.org/10.2112/SI103-205.1

Zuo X, Dong M, Gao F, Tian S (2020) The modeling of the electric heating and cooling system of the integrated energy system in the coastal area. J Coast Res 103(sp1):1022. https://doi.org/10.2112/ SI103-213.1