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Testing Non-Linear Nexus between Service Sector and CO_2 Emissions in Pakistan

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Received: 22 December 2019; Accepted: 14 January 2020; Published: 21 January 2020

Abstract: Our pioneer study is aimed at investigating the role of the service sector in affecting sustainable environment in Pakistan. Using time series data over 1971–2014 and applying an autoregressive distributive lag (ARDL) model with structural break analysis, we establish a long-term equilibrium relationship of carbon dioxide (CO_2) emissions with energy consumption, income level, services and trade openness. Our findings support a service-induced environmental Kuznets curve (EKC) hypothesis in Pakistan. The income level sharply raises environmental degradation at the early stage; however, after reaching a certain threshold, it improves environmental quality but at a lower rate. There exists an inverted U-shaped nexus between services and CO_2 emissions, which implies that the service sector is less energy-intensive in terms of mitigating pollution in Pakistan. Moreover, the energy consumption has an inverted U-shaped effect on carbon emissions, which implies energy efficiencies and adoption of renewable energy has reduced pollution in the long run. The trade openness increases CO_2 emissions in both the short term and long term. The quadratic term of income level has a negatively inelastic impact on CO_2 emissions, which implies a very slow rate of improvement in environmental quality. On the other hand, the quadratic term of services shows a highly elastic impact on pollution, which induces the EKC hypothesis. Our robustness checks such as fully modified ordinary least squares (FMOLS), dynamic ordinary least squares (OLS), and Toda and Yamamoto (TY) causality tests further confirm the existence of the service-induced EKC hypothesis in Pakistan. Moreover, there exists a unidirectional causality from energy consumption to CO_2 emissions, a bidirectional causal relationship between economic growth and CO_2 emissions, and a unidirectional causal linkage between services and CO_2 emissions. Lastly, we discuss certain policy implications for designing appropriate environmental and energy policies to mitigate the pollution in Pakistan.

Keywords: CO_2 emissions; economic growth; EKC hypothesis; service sector; structural change hypothesis

1. Introduction

Structural changes not only brought substantial economic growth in the world but they also raised the issues of environmental degradation and sustainable development [1]. At the earlier stage of development, economic activities shifted from agriculture to manufacturing in the world; however, later on, emergence of the service sector showed tremendous growth, becoming the largest sector of the world economy. The contribution of services to world gross domestic product (GDP) and employment level remarkably increased, while the value addition of the agriculture and manufacturing sector to

GDP declined. The service sector not only provides the highest level of output and employment, but it also stimulates a substantial increase in foreign trade, investments, and service-related exports over the globe [2]. Over the last two decades, the valued-added contribution of the service sector to GDP increased from 69% in 1997 to 74% in 2015 in high-income countries, and surged extraordinarily from 48% in 1997 to 57% in 2015 in developing countries [3]. The provision of services mainly depends upon the building infrastructure, transportation system, and power generation mechanism. According to the International Energy Agency (IEA) [4] report, the transport and building sector accounts for approximately one-half of CO_2 emissions from fossil-fuel burning in the world after redistributing emissions from power generation to sectors. The report further indicates that electricity power generation in Asia caused almost a 50% increase in global emission over the period of 2000–2017, and China and India alone are increasing such emissions by 200 metric tons per annum. These facts and figures highlight the increasing vitality of the service sector to economic growth, while simultaneously raising concerns for unprecedented energy demand and environmental degradation.

The idea of structural change was introduced by Kuznets [5], who identified the shift in sectoral employment from agriculture to manufacturing and the service sector during the path of economic growth. Structural changes may significantly affect sustainable economic growth because of technological progress and the element of uncertainty [6]. However, a higher level of energy consumption requirements, especially in emerging economies, may distort the notion of such sustainable growth [7]. Structural change in the economy may influence the bell-shaped relationship, which we call the environmental Kuznets curve (EKC), between economic growth and environmental degradation [8]. The EKC hypothesis holds that pollution increases at the initial stage of economic development due to industrialization and urban development. However, at the advanced stage of economy, when the service sector grows and technology improves, people get more concerned about environmental issues, they demand a better and more sustainable environment, and pollution consequently tends to decrease [9–11].

A large number of studies investigated the EKC theory in empirical settings based upon different sample characteristics and time spans, as well as applying a variety of econometric approaches. For instance, many researchers confirmed the existence of an inverted U-shaped nexus between economic growth and pollution [12–16]. The evidence on the EKC hypothesis in previous studies is quite controversial, and a large number of studies did not support an inverted U-shaped relationship between economic growth and CO_2 emissions [17–19]. Another set of studies reported mixed evidence relating to the EKC hypothesis due to variations in country dynamics and the type of pollution measures taken [20,21]. Miah et al. [22] argued that global literature on EKC hypothesis provides mixed results depending upon the type of greenhouse gas (GHG) emissions taken as a measure of environmental degradation in empirical research. Marsiglio, Ansuategi and Gallastegui [8] argued that the negative relationship between pollution and income level, as suggested by the EKC hypothesis, is a short-term phenomenon, and that pollution may increase in the long run, generating an N-shaped curve.

Relatively few studies empirically tested the environmental Kuznets curve (EKC) hypothesis with respect to structural change theory; in particular, the role of the service sector in explaining the bell-shaped relationship between economic development and environmental degradation was overlooked in empirical research. The structural transition and growth of the service economy may decrease environmental degradation [23]. Marsiglio et al. [8] also pointed out that the negative effect of income on pollution may depend upon the nature of structural change in the economy. Structural shifts to the service sector could possibly explain the existence of the EKC hypothesis, particularly in developing economies, which are facing the issue of premature deindustrialization [24]. The past literature on the role of services in affecting environmental degradation is not only highly inconclusive but it also did not explicitly test the EKC hypothesis. Some studies argued that services positively affect pollution. For instance, Suh [25] reported that services in the household sector produce more than one-third of total industrial air pollution when both the household consumption of services and the supply-chain network are accounted for. Moreover, Ali et al. [18] pointed out in their empirical research that the service sector is more efficient than the energy-intensive industrial sector in terms of reducing CO_2 emissions. The service sector, which was earlier considered immaterial with regard to consumption of energy, now heavily depends upon energy and material items, which cause pollution and raise concerns for climate change [26]. This immateriality notion was also challenged by Piaggio et al. [27] who explained the increasing role of the service sector in producing CO_2 emissions, as the provision of services produces both direct emissions (as caused by the transport sector) and indirect emissions (due to its inputs produced by other highly energy-intensive sectors). However, Zaman et al. [28] evidenced that the service sector reduces pollution in the world, while the manufacturing sector increases global emissions. Sohag et al. [1] showed the positive impact of the industrial and service sectors on environmental degradation in middle-income countries, which are undergoing massive structural transitions.

The controversial and contradictory findings indicate that the relationship between the service sector and pollution varies across countries due to different levels of economic growth, rates of industrialization and technological advancement, scales of urban growth, and regional differences. Therefore, the results of these prior studies cannot be generalized, which motivates us to investigate the role of the service sector in affecting environmental degradation and whether it affects the inverted U-shaped relationship between income and pollution, so as to gain a deep understanding of this complex relationship. Therefore, the purpose of our study is to examine the non-linear effect of the service sector on carbon emissions over the time period of 1971–2014 using an autoregressive distributive lag (ARDL) model.

Our study contributes to the existing literature in many aspects. Firstly, our research investigates the long-term relationship between the service sector and environmental degradation in Pakistan. We selected the service sector because it is the largest sector, and it showed a tremendous growth of 6.43% over the last two years, which is larger than that of the agriculture and manufacturing sectors. Furthermore, it contributes to more than 50% of the GDP, and it offers major employment to the labor force [29]. The service sector consists of retailing and wholesaling, financial services, transportation and storage, communication and information technology (IT), government services, housing, and other private services in Pakistan. Figure 1 exhibits how the structural change in Pakistan caused splendid growth as compared to the agriculture and industrial sectors, which showed declining trends in the economy. Secondly, our research is original and innovative because we are the first to analyze the role of the service sector in inducing an inverted U-shaped relationship between economic growth and pollution, which was overlooked in previous studies, especially in Pakistan. Moreover, the contradictory results regarding the role of the service sector in mitigating emissions requires further investigation so as to gain further insight and implement policy formulation. Therefore, we investigate the non-linear effect of services on environmental degradation to clearly determine the pollution reduction role of service sector. Thirdly, we apply an autoregressive distributive lag (ARDL) model with structural break analysis to account for any economic shocks, which could have biased or skewed the previous findings on the EKC hypothesis. The major structural changes which occurred in the 1980s and 1990s in Pakistan due to liberalization and major economic reforms could have substantially affected EKC results under a traditional econometric approach. Fourthly, we also examine the inverted U-shaped effect of energy consumption on carbon emissions to support the pollution-mitigating role of services. Lastly, we apply fully modified ordinary least squares (FMOLS) and dynamic ordinary least squares (DOLS) to confirm our previous findings, and we utilize the Toda and Yamamoto (TY) causality approach as used by Ahmed et al. [30] to investigate causal interactions between variables.

The rest of the paper is structured as follows: in the forthcoming section, we undertake a critical and systematic review of the literature to identify research gaps. The third section describes the methodology consisting of model construction, data collection and variable description, unit root and structural break testing, and econometric modeling. In the fourth section, we elaborate on the mainstream results and discuss important findings. In the fifth section, the robustness tests were applied in terms of DOLS and Toda and Yamamoto causality tests to confirm our baseline model. Lastly, we conclude the study with major findings, policy implications, and directions for the future.

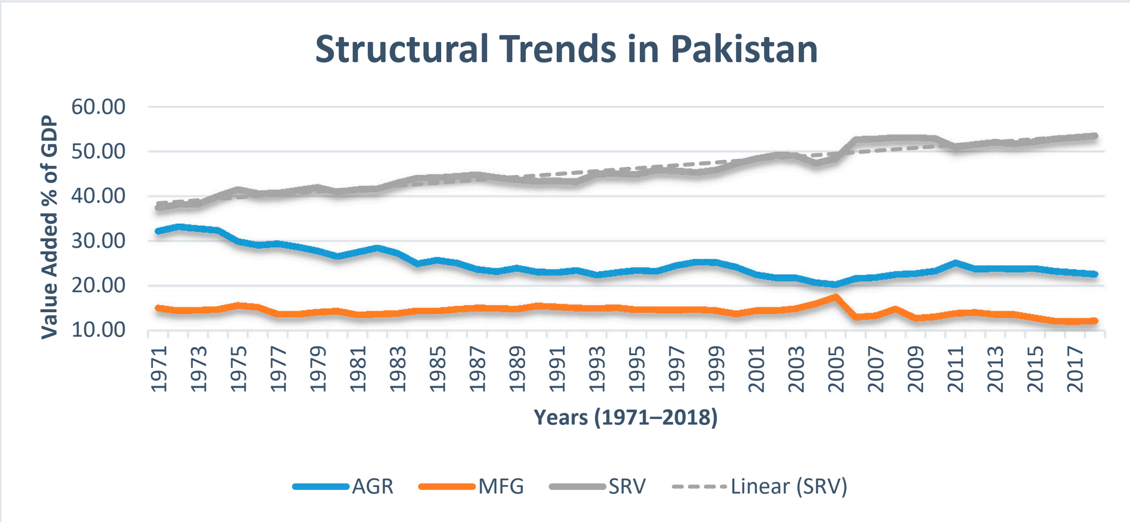


Figure 1. Sector-wise trends over the 1971–2014 period in Pakistan. Source: authors' interpretation based on World Development Indicators (WDIs).

2. Literature Review

This section provides a comprehensive and systematic review of the famous environmental Kuznets curve (EKC) hypothesis, expressing an inverted U-shaped or bell-shaped relationship between economic growth and environmental degradation. We divide the prior literature into three categories, namely, individual country studies, cross-country studies, and structural change studies, for a better understanding and research gap identification. Although the EKC phenomenon was extensively studied over the globe, the findings varied from one country to another and from one region to another due to sampling characteristics, estimation procedures, regional differences, panel heterogeneity, modeling limitations, and country-specific dynamics.

2.1. Single-Country Studies

Several studies investigated the inverted U-shaped nexus between income and pollution at the country level, but the findings were mixed depending upon the additional factors taken into account, pollution measurement proxies, and econometric modeling. For example, Roca et al. [21] tested the income-pollution nexus using six different types of air pollution in Spain. Their results refuted the EKC for all pollutants except sulfur dioxide (SO_2), and they argued that several other factors other than income level could potentially affect air pollution. Similarly, Lantz et al. [31] examined the role of technology, population, and economic growth in environmental degradation in five regions of Canada. Their findings did not confirm an inverted U-shaped relationship between income and CO_2 emissions; however, they supported the existence of a U-shaped relationship between CO_2 emissions and technology, as well as an inverted U-shaped link with population.

Mazzanti et al. [32] used provincial data related to waste management in Italy to confirm delinking of provincial economic growth with waste pollution. However, their findings indicated that the turning point of such an EKC was higher than the average regional value. Ali et al. [18] did not find support for an EKC curve in Malaysia using an ARDL model and Granger causality test. Alshehry et al. [33] investigated the EKC hypothesis in the road transport sector in Saudi Arabia. Their findings rejected the existence of an inverted U-shaped curve between economic growth and transport pollution. Cosmas et al. [34] refuted the existence of an EKC in Nigeria by examining both linear and non-linear effects of economic growth on environment using ARDL and nonlinear autoregressive distributive lag (NARDL) models. They showed that an N-shaped curve holds in Nigeria. These findings indicate that the EKC theory may not produce expected results due to omitted variable bias, sampling period, econometric methodology, regional dynamics, and type of pollution emissions undertaken in a research study.

On the other hand, there were several studies which successfully tested the EKC hypothesis. For instance, using three types of pollutants such as solid waste, gas waste, and water pollution as measures of environmental degradation, Song et al. [35] successfully examined the income-pollution nexus for all three pollutants across regions in China. Shahbaz et al. [15] showed the long-term relationship between CO_2 emissions and economic growth, energy use, and trade openness, and an EKC was confirmed in Pakistan. Al-Mulali et al. [10] witnessed an inverted U-shaped curve of environmental degradation in Kenya. Their results showed that trade openness, income, and energy consumption worsened the environmental quality, while financial development helped mitigate the pollution.

Ozturk et al. [36] documented that economic growth, trade openness, energy use, and urbanization worsened the environmental quality in Cambodia. However, they found a mitigating role of corruption control and good governance in environmental degradation. Pata [37] investigated the positive effect of economic growth, financial development, urbanization, and trade openness on pollution in Turkey, and he also confirmed an inverted U-shaped nexus between economic development and environmental degradation. The environmental Kuznets curve was also tested in a recent study by Khan et al. [38] who confirmed the bell-shaped relationship between income and pollution in Pakistan. In previous studies, the relationship between economic growth and CO_2 emissions was also augmented by several other indicators such as energy consumption, transportation, tourism, financial investment, trade openness, energy mix, heath expenditure, and industrialization [39].

Previous research studies examined the role of different sectors such as the oil, energy, transportation, agriculture, and manufacturing sectors in augmenting the EKC hypothesis in different settings. For instance, Katircioğlu [40] documented the negative effect of tourism on pollution using an ARDL approach. They reported that the tourism sector induces an inverted U-shaped nexus between economic development and environmental degradation. Katircioglu [41] investigated the negative effect of oil prices on CO_2 emissions. They supported an oil-induced EKC phenomenon in Turkey using cointegration and causality tests. Danish et al. [12] investigated the role of energy production in augmenting the EKC in Pakistan using an ARDL approach. Their findings confirmed a feedback relationship between CO_2 emissions and the EKC and energy production. Gokmenoglu et al. [42] evidenced the role of the agriculture sector in explaining the environmental Kuznets curve (EKC) hypothesis in Pakistan using cointegration and causality tests. Applying decoupling analysis on industrial sectors in China, Yang et al. [43] documented an inverted U-shaped relationship between the manufacturing sector and CO_2 emissions. However, their findings indicated large variations in the mitigation effect of the industrial sector. Usman et al. [13] documented that democracy and energy induce the EKC hypothesis in India. However, in these studies, the role of the service sector in explaining the income-pollution nexus was ignored, and this requires further investigation in testing the service-augmented EKC theory in different country settings.

2.2. Cross-Country Studies

An abundance of literature is available pertaining to the income-environmental degradation inverted U-shaped relationship, and the results varied greatly due to the heterogeneity of countries, regional growth factors, and limitations of panel cointegration techniques.

Jebli et al. [44] studied the EKC hypothesis in OECD (Organization for Economic Cooperation and Development) countries by including other important factors such as trade and energy types. Their findings concluded that an inverted U-shaped relationship holds for sample countries, and that renewable energy and international trade mitigate environmental degradation. The cross-sectional study of Zaman et al. [28] confirmed a bell-shaped income-pollution nexus, and their findings supported that sectoral growth and energy use induced emissions over the globe. Zhang et al. [14] verified a hypothetical EKC in 10 newly industrialized countries by applying panel cointegration and Granger causality tests. Acheampong [45] successfully confirmed the EKC hypothesis at the global and regional level for 116 countries.

Sarkodie [46] examined the determinants of environmental quality of 17 African countries. Their findings confirmed the existence of EKC for the pollution-income nexus, and he found a U-shaped relationship between income and ecological footprint. Moreover, his results indicated that other factors such as food production, energy consumption, birth and fertility rates, agriculture, and permanent crops also cause environmental degradation. These findings support the EKC at a global level and in sub-Saharan Africa. Ahmad et al. [47] carried out a provincial-level study in China, and their findings supported the existence of both a conventional EKC curve and an augmented EKC based on financial development and trade openness in all regions except the western region. Cansino et al. [48] confirmed an EKC in 18 Latin American countries. Their findings also indicated that technological progress and institutional quality mitigate environmental degradation. Yilanci et al. [49] tested the income-pollution nexus in G7 countries using a bootstrap causality test. Their findings showed that an EKC exists in the United States of America (USA) and Japan only, while an inverted U-shaped effect did not appear in other countries. However, some studies also documented contradictory results and, in some cases, did not observe the EKC phenomenon in their sample countries. For example, Lee et al. [50] utilized cross-country data to examine the income-pollution nexus at a global and regional level using generalized methods of moments (GMM). They could not empirically test EKC at the global level but confirmed the underlying relationship in America and Europe. However, such an inverted U-shaped relationship was not observed in Asia, Oceania, and Africa. Onafowora et al. [20] provided mixed results for EKC in selected Asian, African, and Latin American countries. Their findings supported the EKC hypothesis for Japan and South Korea, while other countries showed N-shaped trajectories using an ARDL bounds testing procedure.

Ozturk et al. [51] evidenced the EKC hypothesis in 144 countries, and their findings indicated that the negative effect of tourism GDP, trade liberalization, and energy use is more prevalent in upper-middle-income and high-middle-income countries. Zoundi [52] found no evidence of the EKC hypothesis for selected African counties. Liu et al. [53] investigated the inverted U-shaped relationship between economic growth and environment in three east Asian countries, namely, Korea, Japan, and China. They evidenced the existence of the EKC hypothesis in Japan and Korea only, and no such relation was observed in China. Kisswani et al. [19] examined the effect of economic growth on CO_2 emissions in five Association of Southeast Asian Nations (ASEAN) countries using ARDL with structural break analysis for individual countries and a pooled mean group (PMG) estimator for overall sample. They found that the inverted U-shaped hypothesis does not hold for these countries, except for Thailand after incorporating structural breaks in the model.

2.3. Structural Change Studies

The structural change hypothesis holds that an economy initially shifts from the low-pollution agriculture sector to the high-pollution industrial sector, and then eventually to the low-pollution service sector [8]. Several studies examined the effect of structural changes on environmental quality. For example, Han et al. [54] studied the effect of the industrial structure, economic growth, energy efficiency, and energy mix on CO_2 emissions of nine developing countries over the period of 1972–1990 using decoupling analysis. Their findings indicated that the GDP and industrial sector have a positive effect on CO_2 emissions. Diakoulaki et al. [55] checked the effect of industrial growth on CO_2 emissions in 14 EU (European Union) countries, and they found that the decoupling effect did not accelerate much in the post-Kyoto era. They concluded that the Kyoto Protocol did not achieve the desired targets in the manufacturing sector. Changes in industrial structure significantly affect CO_2 emissions. Chen et al. [56] documented the positive effect of industries such as mining, construction, and heavy industries in China on CO_2 emissions. However, light manufacturing showed a declining pattern with respect to CO_2 emissions.

Hocaoglu et al. [57] applied a hidden Markov model to estimate CO_2 emissions from industrial growth in G7 countries, and they found a positive effect of industrial growth on CO_2 emissions. Ahmad et al. [58] evidenced the positive effect of industrial growth and population on CO_2 emissions in the South Asian Association for Regional Cooperation (SAARC) region by applying a panel cointegration test. Bekhet et al. [59] documented the bidirectional causal relationship among industrial share, energy use, and CO_2 emissions, while unidirectional causality existed between economic growth, population, and trade and CO_2 emissions. The study found a negative effect of industrial share on CO_2 emissions in Malaysia, while energy consumption and trade openness had a positive effect on CO_2 emissions. The study did not support the ECK hypothesis. Rahman et al. [60] found a positive effect of industrial growth and energy consumption on CO_2 emissions in Bangladesh. Their findings indicated a unidirectional relationship between industrial growth and CO_2 emissions.

Yang et al. [43] studied the effect of structural change on CO_2 emissions using provincial data of China, and their results indicated that the manufacturing and transportation sectors are the largest emitters of CO_2. They also identified an inverted U-shaped decoupling effect of manufacturing on CO_2 emissions. Liang et al. [61] tested the effect of energy intensity, industrial structure, CO_2 emission intensity, energy structure, and GDP and population growth on CO_2 emissions. The study concluded that industries with a high energy consumption requirement are increasing CO_2 emissions in China. Moreover, the effect of GDP and population on CO_2 emissions was positive and showed weak decoupling. Wang et al. [62] verified the sectoral level decoupling effect on CO_2 at the city level in China. They found that population growth and income level reduced the decoupling effect, while industrial share, energy intensity, and energy mix improved the decoupling effect. Chen et al. [63] studied the effect of industrial agglomeration on CO_2 emissions by investigating 187 cities. Their empirical findings supported the positive effect of agglomeration on CO_2 emissions, while such industrial agglomeration activities in China reduced the CO_2 intensity of industrial production, which is quite favorable for the Chinese government achieving its targets in 2020.

There were several studies which examined the effect of the service sector on pollution, but they did not explicitly test the EKC hypothesis in their empirical analysis. Moreover, the findings of these studies are controversial in explaining whether the service sector enhances environmental degradation or not. Okamoto [23] investigated the effect of a structural transition to the service industry in Japan using decomposition analysis, and he documented that the service industry reduced CO_2 emissions in Japan over the period 1995–2005. Li et al. [64] applied an input–output model and social-network analysis in a comparative study of Japan and China. They argued that industrial adjustment and connectivity among various industries is improving in China, but its industrial transition process still needs to be improved to mitigate CO_2 emissions as Japan moves more toward the service sector.

Sohag et al. [1] carried out a panel study of 83 middle-income countries for the period 1980–2012, and they found a positive effect of energy use and sectoral output on CO_2 emissions. A summarized view of selected EKC studies is provided in Table 1, which exhibits the sample type, time period, econometric modeling, and major findings of these research papers. These findings indicate that the issue of the income-pollution nexus and its related EKC hypothesis still requires further research, as the results of prior studies were not consistent due to several factors as mentioned in the literature. In particular, the role of the service sector, which is commonly perceived as a lower pollution generating sector, was either neglected or it was not directly tested in augmenting EKC theory. Therefore, we examined the role of the service sector in explaining the income-pollution inverted U-shaped relationship in Pakistan.

Table 1. Snapshot of selected EKC studies.

	Author	Country	Period	Sector	Methodology	EKC Confirmed
Single Country Studies	Suh [25]	USA	CS	SRV	Descriptive Analysis	Not Tested
	Song at al. [35]	China	1985–2005	No	Panel Cointegration with DOLS	Yes
	Nansai et al. [26]	Japan	1990–2000	SRV	Qualitative Analysis	Not Tested
	Piaggio et al. [27]	Uruguay	2004	SRV	Input-Output Analysis	Not Tested
	Ali et al. [18]	Malaysia	1971–2013	MFG	ARDL with Granger Causality	No
	Alshehry et al. [33]	Saudi Arabia	1971–2011	TSP	ARDL with Granger Causality	No
	Danish et al. [12]	Pakistan	1971–2011	ENG	ARDL with Granger Causality	Yes
	Gokmenoglu et al. [42]	Pakistan	1971–2014	AGR	Maki (2012) Cointegration, and TY Causality Tests	Yes
	Usman e al. [13]	India	1971–2014	No	ARDL and VECM	Yes
Cross-Country/ Regional Studies	Onafowora et al. [20]	8 C	1970–2010	No	ARDL with VDCA	Mixed Results; Inverted U & N-Shaped
	Zhang et al. [14]	10-NIC	1971–2013	No	Panel Cointegration with VECM	Yes
	Zoundi [52]	25 African C	1980–2012	No	Panel Cointegration, Panel ARDL, GMM and DOLS	No
	Sohag et al. [1]	MIC	1980–2012	3 S	AMG and CCMEG	Not Tested; SRV & IND has +E
	Acheampong [45]	116 C	1990–2014	No	GMM Panel VAR	Yes, for global & Sub-Saharan Africa
	Kisswani et al. [19]	5-ASEAN	1971–2013	No	ARDL With Structural Break; PMG and Granger Causality	Only for Thailand, overall not confirmed
	Cansino et al. [48]	18 LAC	1996–2013	No	Panel Regression Model	Yes
	Yilanci et al. [49]	G-7	1970–2014	No	Bootstrap panel causality test	Mixed Results
	Ahmad et al. [47]	China	1997–2016	No	DCCEMG	Yes, except W-Region

Note: C—country; CS—cross sectional; SRV—service sector; MFG—manufacturing sector; AGR—agriculture; TSP—transportation; DOLS—Dynamic Ordinary Least Squares; ARDL—Autoregressive Distributive Lag Model; TY—Toda Yamamoto Causality Test; VECM—Vector Error Correction Model; MG—Mean Group Estimator; PMG—Pooled-mean Group Estimator; DFE—Dynamic Fixed Effect; VDCA—Vector Decomposition Analysis; GMM—Generalized Method of Moments; EKC—Environmental Kuznets Curve; AMG—Augmented Mean Group Estimator; CCMEG—Common Correlated Mean Effects Group Estimator; VAR—Vector Autoregression; DCCEMG—Dynamic CCEMG; +E means positive effect; NIC—Newly Industrialized Countries; LAC—Latin American Countries; ENG—energy sector; 3 S are three sectors of the economy.

3. Materials and Methods

The inverted U-shaped nexus of economic development, the service sector, and environmental degradation was empirically examined by implementing a robust methodology. Firstly, our model was constructed based upon EKC theory. Secondly, the variables and data sources pertaining to our model were investigated, and their proxies and validity were also discussed. Thirdly, the issue of unit root was investigated to determine the order of integration of our variables of interest. Fourthly, the structural break test was performed to identify any structural break years. Lastly, the econometric model used for investigating the EKC hypothesis was elaborated on and justified.

3.1. Model Construction

As discussed in the literature review, the EKC theory holds a bell-shaped nexus between economic growth and environmental degradation. Previous studies postulated that economic growth causes environmental damage in terms of pollution to a certain threshold, and then it improves the environmental quality as people become more concerned about the environmental problems due to their higher living standards [10,11,15,33,65,66]. Prior researchers stated this inverted U-shaped relationship by taking the quadratic term of income level Y [50,53,67]. The generalized functional form of the EKC model can be expressed as follows:

$$CO_{2t} = F\left(E_t, Y_t, {Y_t}^2\right), \quad (1)$$

where CO_2 indicates carbon dioxide emissions (expressed in metric tons per capita), E denotes energy consumption (kilograms of oil equivalent per capita), Y is the GDP per capita, and Y^2 denotes the squared term of the GDP per capita to capture the EKC hypothesis. In this equation, CO_2 is a non-linear function of energy consumption and economic growth. We extended this baseline model to incorporate our structural variable, namely, services (S) and control variable trade openness (T). Our augmented or service-induced EKC model takes the following functional form:

$$CO_{2t} = F\left(E_t, Y_t, Y^2{}_t, S_t, T_t\right), \quad (2)$$

In Equation (2), CO_2 is expressed as a non-linear function of energy consumption, economic growth, services, and trade openness. The generalized model in Equation (2) was usually expressed in logarithmic transformation in many previous studies due to its several advantages over a simple linear form [15,47,68]. This allows calculating the elasticities of our regressors with respect to CO_2 emissions which are easy to interpret. Moreover, a logarithmic transformation could be used for data smoothing and normalization [38]. Following the study of Khan et al. [38], the log form is given as follows:

$$\ln CO_{2t} = \beta_0 + \beta_1 \ln E_t + \beta_2 \ln Y_t + \beta_3 \ln {Y_t}^2 + \beta_4 \ln S_t + \beta_5 \ln T_t + \mu_t, \quad (3)$$

where CO_2 denotes carbon emissions, Y is the GDP per capita, Y^2 is the quadratic value of the GDP per capita, S represents the value added of the service sector, T is the trade openness, and μ_t is the error term of the model representing other factors. All these variables were transformed into a logarithmic form for a smoothening effect. The coefficients ranging from β_1 to β_5 are the coefficients of energy consumption, income level, quadratic term of income level, services, and trade openness, respectively. Based on previous discussion, we assumed that energy consumption has a positive effect on pollution as measured by CO_2 [15,30]. More energy use is expected to worsen the environmental quality, and its expected coefficient sign should be positive ($\beta_1 > 0$).The coefficient of income level and its quadratic term should be positive and negative, respectively ($\beta_2 > 0$; $\beta_3 < 0$), based on the EKC theory which proposes that economic development increases environmental degradation to a certain level; it then improves the environmental quality because a higher income level makes people more concerned about environmental problems and health issues. The effect of the service sector on CO_2 emissions could be either positive or negative, because it depends upon the share of services in the overall GDP and its degree of dependency on the manufacturing sectors for the provision of various inputs to the service sector in a country [27]. This is the basic premise of our research investigating how the service sector affects the emissions. However, we also added the quadratic term of services to investigate the non-linear effect of services on environmental degradation in Pakistan. Since there was a major structural shift from the agriculture sector to the service sector as compared to the industrial sector in the country, we expected an inverted U-shaped relationship between services and CO_2 emissions. This inverted U-shaped relationship would actually support the role of the service sector in inducing the EKC hypothesis in Pakistan. Therefore, we checked the non-linearity of services using the following equation:

$$\mathrm{lnCO}_{2t} = \alpha_0 + \alpha_1 \mathrm{lnE}_t + \alpha_2 \mathrm{lnY}_t + \alpha_3 \mathrm{lnS}_t + \alpha_4 \mathrm{lnS}_t{}^2 + \alpha_5 \mathrm{lnT}_t + \mu_t, \quad (4)$$

where CO_2 stands for carbon dioxide emissions, E denotes energy consumption, Y denotes income level, S denotes services, S^2 is the quadratic term of services, and T is trade openness. All time-series were converted into natural log form for data smoothening. The coefficients ranging from α_1 to α_5 show the long-term elasticities of our regressors. If the coefficient of services ($\alpha_3 > 0$) is positive and the coefficient of its quadratic term ($\alpha_4 < 0$) is negative, the inverted U-shaped impact of services on pollution holds in Pakistan, which exhibits the pollution-mitigating role of the service sector in the country. Trade openness could also have either a positive or a negative effect on pollution in the country. If trade openness is linked to environmental policy in the host country and if it brings environmentally friendly technology, it could then have a favorable impact on the environmental quality [15,67].

We also modeled the quadratic term of energy consumption in Equation (5) to check its non-linear effect on CO_2 emissions in Pakistan. The basic intuition behind this log is that energy use and carbon emissions are tightly linked during the early phase of economic development and structural change. However, the development of more environmentally friendly and energy-efficient technology and a shift toward cleaner energy production decrease environmental degradation [69]. Therefore, we expected that the quadratic term of energy use should hold a negative coefficient ($\alpha_2 < 0$), which implies that a more efficient use of energy and cleaner production mitigate pollution in Pakistan.

$$\mathrm{lnCO}_{2t} = \alpha_0 + \alpha_1 \mathrm{lnE}_t + \alpha_2 \mathrm{lnE}_t{}^2 + \alpha_3 \mathrm{lnY}_t + \alpha_4 \mathrm{lnS}_t + \alpha_5 \mathrm{lnT}_t + \mu_t, \quad (5)$$

where CO_2 denotes carbon emissions, E is the energy consumption, E^2 is the quadratic term of energy consumption, Y is the GDP per capita, S denotes services, and T denotes trade openness. All variables were taken in logarithmic form.

3.2. Variable Description and Data Collection

All variables were time series over the period of 1971–2014. CO_2 represents CO_2 emissions in metric tons per capita [18], energy consumption (E) was measured in kilograms of oil equivalent per capita [15], economic growth (Y) was represented by GDP per capita (in constant 2010 US dollars) [13], and Y^2 represents the quadratic term of GDP per capita to investigate the inverted U-shaped phenomenon. Additionally, the services (S) term was measured in terms of value added of the service sector as a percentage of GDP [1], and trade openness (T) was measured in terms of trade as a percentage of GDP [47]. The quadratic term of services was also added to determine the pollution reduction role of services in Pakistan. The value-added contribution of services as a percentage of services was used in prior studies because it represents the growth and magnitude of the service sector in a country [1,27]. Moreover, other measures of the service sector such as input–output longitudinal data were neither available from the World Bank nor the concerned authorities of Pakistan. Therefore, the input–output analysis of services in conjunction with other sectors was not the main concern of our research and fell outside the scope of the study. According to World Bank Indicators, the value-added figure of services includes sub-sectors of services such as transportation, financial institutions, professional services, the education industry, healthcare and hospital services, real estate services, retailing and wholesaling services, hotels, and restaurants. We used the value-added output of the service sector as a percentage of GDP.

Carbon dioxide (CO_2) was expressed in metric tons per capita. Carbon dioxide is one of the several types of greenhouse gas (GHG) emissions, which include CO_2, methane (CH_4), nitrous oxide (N_2O), and fluorinated gases. According to statistics of the Environmental Protection Energy (EPA), CO_2 is the major source of pollution in the world [70]. Moreover, the main anthropogenic activities producing carbon dioxide include the burning of fossil-fuel energy resources such as oil, coal, and natural gas for transportation, energy production, residential housing, industrial processes, and changes in land forms such as the depletion of forests and natural resources. Table 2 exhibits the symbolization of variables, their respective proxies, and the sources of data collection. All data relating to CO_2 emissions, economic growth, services, energy use, and trade openness were downloaded from the World Development Indicators (WDIs) available on the website of the World Bank. All time-series variables were converted into natural logarithmic form to represent our final EKC model in Equation (5).

Table 2. Variable description and measurement. GDP—gross domestic product; WDI—World Development Indicator; US—United States.

Variables Used	Symbol	Proxy Used	Data Sources
CO_2 emissions	$\ln CO_2$	CO_2 emissions metric ton per capita	WDI
Energy consumption	lnE	Kilograms of oil equivalent per capita	WDI
Quadratic term of energy consumption	$\ln E^2$	Squared term of kg of oil equivalent per capita	
Income level	LnY	GDP measured in constant 2010 US $ per capita	WDI
Quadratic term of GDP	$\ln Y^2$	Squared term of GDP per capita (constant 2010 US $)	-
Services	LnS	Services value added as percentage of GDP	WDI
Quadratic term of services	$\ln S^2$	Squared term of valued added as percentage of GDP	-
Trade openness	LnT	Trade openness as the total of imports and exports (goods and services) as a percentage of GDP	WDI

3.3. Unit Root Test

Before applying a regression or cointegration model, it is imperative to determine the data stationarity or order of cointegration of the dependent and independent variables. For this purpose, unit root tests are applied in econometric analysis to mitigate the issue of spurious regression. We performed augmented Dickey et al. [71] and Phillips et al. [72] unit root tests to check whether our variables were stationary at level or at first difference, or if they had a mixed order of integration. These tests were widely used in previous studies to determine the order of integration [18,30,65]. The line graphs of our variables also indicate the time series trends over the period 1971–2014, as shown in Figure A1 (Appendix A) at the end of the paper.

Since the first-generation unit root tests such as ADF and PP could give misleading and biased results in the presence of structural breaks existing in time series, we also applied the widely utilized structural break test of Zivot et al. [73]. The Zivot and Andrews (ZA) test allows identification of a single break at any time, which mitigates the problems associated with the ADF, PP, and Kwiatkowski-Phillips-Schmidt-Shin (KPSS) tests, and addresses small sample biases [12,30,42].

Table 3 reports the unit root results using ADF and PP tests for our variables both at level and at first difference. Our ADF and PP results showed that all our variables, including CO_2 emissions, energy use, GDP, and services, were stationary at first difference, while trade openness was stationary at level. Moreover, the results of the ZA test also exhibited the same pattern and indicated that all variables were stationary at first difference, except for trade openness which had an I(0) order of integration. Moreover, no variable had a second order of integration, which warranted use of an autoregressive distributive lag (ARDL) model for further investigation of short-term and long-term relationships among our variables of interest.

Table 3. Checking data stationarity using unit root tests.

Variable Name		ADF TEST		PP Test		ZA Test	
		C	**C + T**	**C**	**C + T**	***t*-Value**	**Break Year**
Level	$lnCO_2$	−0.618	−1.747	−0.612	−2.192	−2.903	2018
	lnE	−1.880	0.339	−1.771	0.339	−1.307	2007
	lnY	−1.576	−1.597	−0.900	−1.510	−3.751	1980
	lnY^2	−1.305	−1.770	−0.691	−1.720	−3.743	1980
	lnS	−1.432	−2.889	−1.467	−2.996	−4.454	2005
	lnS^2	−1.366	−2.836	−1.382	−2.951	−4.534	2005
	lnT	−5.954 ***	−5.508 ***	−5.764 ***	−5.390 ***	−7.222 ***	1998
First Difference	Ϫ$lnCO_2$	−4.682 ***	−10.296 ***	−8.855 ***	−10.291 ***	−11.562 ***	2008
	ϪlnE	−5.160 ***	−5.697 ***	−5.185 ***	−5.697 ***	−7.224 ***	2008
	ϪlnY	−5.708 ***	−5.889 ***	−5.751 ***	−5.892 ***	−6.397 ***	1993
	ϪlnY^2	−5.565 ***	−5.649 ***	−5.575 ***	−5.649 ***	−6.134 ***	1993
	ϪlnS	−5.819 ***	−5.791 ***	−6.155 ***	−6.063 ***	−6.149 ***	1993
	ϪlnS^2	−5.811 ***	−5.774 ***	−6.144 ***	−6.036 ***	−6.133 ***	1993
	ϪLnT	−8.309 ***	−8.297 ***	−11.873 ***	15.613 ***	−8.769 ***	2001
Critical Values	1% level	−3.597	−4.192	−3.597	−4.192	−5.340	
	5% level	−2.935	−3.521	−2.935	−3.521	−4.930	
	10% level	−2.606	−3.191	−2.606	−3.191	−4.580	

Note: *, **, and *** indicate 10%, 5%, and 1% levels of significance; AFD stands for augmented Dicky-Fuller Test; PP indicates the Phillips-Perron test; ZA indicates the Zivot and Andrews test; C means constant, and C + T implies a constant and linear trend.

3.4. Structural Break Analysis

The structural break analysis is important to determine any extraordinary event or economic shock that could cause a sudden change in a time series at a certain point of time. Therefore, structural break tests are used to identify specific break dates before applying cointegration or the ARDL model, because such structural breaks could bias or skew the results of ARDL [19]. Following the study of Kisswani et al. [19], we applied the Bai et al. [74] test to investigate break dates. Bai et al. [74] suggested that this method is preferable over the other structural break tests because it warrants a consistent strategy to simultaneously determine the most suitable break dates while allowing for specific to general econometric modeling.

The results of break analysis are reported in Table 4, which clearly indicates the presence of two break dates, i.e., the years of 1980 and 1990, because the scaled F-test value was greater than the critical value (95.227 > 19.910). During these periods, Pakistan faced major shifts in the economy. The Afghan war started around the 1980s which had a substantial effect on the economic trends in Pakistan. Moreover, the government made structural changes as induced by the International Monetary Fund (IMF) in the country in the early 1990s, which caused major shifts in macroeconomic indicators owing to liberal privatization policies, currency devaluation, reduction of import duties and tariffs, reforms in the financial sector, and a shift from a fixed to flexible exchange rate determination system [47]. We also applied the ZA structural break test to confirm the findings of the Bai–Perron test to allow for stochastic trend and random-walk processes existing in our time series. The results confirmed the findings of the Bai and Perron (1998) test and exhibited that most of the structural breaks occurred in 1980 and 1990. For example, the majority of breaks identified by the ZA test fell near 1990 (i.e., 1993), which was the period of major economic and policy reforms in Pakistan. The results of the ZA structural break test are reported in Table 3 for comparative purposes. Therefore, the results of the structural break tests were perfectly consistent with the structural shifts in Pakistan, especially in the years 1980 and 1990. We incorporated these break dates in the ARDL model to obtain consistent and accurate results.

Table 4. Structural break test (Bai-Perron).

Break Test	F-Stat	Scaled F-Stat	Critical Value	Break Dates
0 vs. 1	18.689	93.447	18.230	1980
1 vs. 2 *	10.045	95.227	19.910	1990
2 vs. 3	1.451	7.253	20.990	

Note: * indicates a 5% level of significance; Bai-Perron (Econometric Journal, 2003) critical values.

3.5. ARDL Model with Structural Break

The objective of our research was to investigate the non-linear effect of the service sector on pollution. Such long-term relationships between our variables undoubtedly depend upon existence of cointegration. Cointegration tests such as Engle and Granger (EG) and Johnson and Juselius (JJ) tests assume that all variables should have the same order of integration or be stationary at first difference [47]. Moreover, the majority of these approaches are applicable for large samples. On the other hand, the autoregressive distributive lag (ARDL) model is the most suitable technique when variables have a mixed order of integration or even when all variables are stationary at level or first difference [75]. However, the results of the ARDL approach become invalid if any of the variables have a second order of integration. The unit root results in Table 3 exhibit that our variables were stationary at level and first difference.

Thus, we applied the ARDL approach to ensure reliable and accurate results of the EKC hypothesis because of the following beneficial properties which cointegration approaches fail to address [19,30,38]:

I. ARDL can give reliable results for small samples.
II. It addresses the endogeneity issue by incorporating an optimal lag length of the variables.
III. It can mitigate the econometric problems of autocorrelation by choosing the maximum lag length of variables.
IV. It simultaneously determines the short-term and long-term effects, and it also measures the speed of adjustment to the equilibrium position with an error correction term (ECT).
V. The ARDL model was also extensively and successfully implemented in prior studies to investigate the inverted U-shaped relationship between economic growth and CO_2 emissions [76–81].
VI. Lastly, it allows incorporating any structural breaks in the model to further investigate the accuracy and stability of the results [19,30].

Equation (6) represents our ARDL model with structural breaks to investigate the long-term and short-term relationships between CO_2 emissions and other variables. The model was divided into two parts.

$$\begin{aligned}\Delta(\mathrm{LnCO_2})_t = {} & \alpha_o+\alpha_{D80}D_{80}+\alpha_{D90}D_{90}+\beta_{CO_2}(\mathrm{LnCO_2})_{t-1}+\beta_E(\mathrm{LnE})_{t-1}+\beta_Y(\mathrm{LnY})_{t-1}+\beta_{Y^2}\left(\mathrm{LnY^2}\right)_{t-1} \\ & +\beta_S(\mathrm{LnS})_{t-1}+\beta_T(\mathrm{LnT})_{t-1}+\sum_{k=1}^{p}\varphi_{1k}\Delta(\mathrm{LnCO_2})_{t-k}+\sum_{k=0}^{p}\varphi_{2k}\Delta(\mathrm{LnE})_{t-k}+\sum_{k=0}^{p}\varphi_{3k}\Delta(\mathrm{LnY})_{t-k} \\ & +\sum_{k=0}^{p}\varphi_{4k}\Delta(\mathrm{LnY^2})_{t-k}+\sum_{k=0}^{p}\varphi_{5k}\Delta(\mathrm{LnS})_{t-k}+\sum_{k=0}^{p}\varphi_{6k}\Delta(\mathrm{LnT})_{t-k}+\mathrm{ECT}_{t-1}+\varepsilon_t\end{aligned} \quad (6)$$

The coefficients in the first part, namely, β_{CO_2}, β_E, β_Y, $\beta_Y{}^2$, β_S, and β_T, represent the long-term parameters measuring the long-term effects of economic growth, the quadratic term of economic growth, services, and trade openness on air pollution. The second part with Σ indicates the short-term effects, and coefficients ranging from φ_1 to φ_6 measure the short-term dynamics of the EKC hypothesis and structural change parameters. The error correction term, represented by $ECT_{t-1,}$ measures the speed of adjustment to the equilibrium position. The dummy variables D_{80} and D_{90} represent the structural breaks occurring in the 1980s and 1990s due to major shifts in economic and trade policies. The analyses for year 1980 and 1993 were also performed, and they are reported in Table A2 for comparative purposes. The results of these structural models confirmed the findings of our mainstream model. The bounds testing procedure developed by Pesaran et al. [75] was carried out to determine the long-term cointegration relationship among our variables. The null and alternate hypotheses of ARDL bounds testing were as follows:

H$_o$: $\beta_{CO_2} = \beta_E = \beta_Y = \beta_Y{}^2 = \beta_S = \beta_T$ *(no cointegration);*

H$_a$: $\beta_{CO_2} \neq \beta_E \neq \beta_Y \neq \beta_Y{}^2 \neq \beta_S \neq \beta_T$ *(cointegration confirmed).*

We can reject the null hypothesis of no-cointegration if the generated F-value is greater than critical values of the lower and upper bounds. If the F-value is greater than the critical bound statistics, the ARDL model is consistent and a cointegration relationship among our variables exists [13,75]. We also conducted diagnostic tests to address econometric issues such as normality, heteroscedasticity, autocorrelation, and functional form, which could have influenced the reliability of our estimates. The stability graphs based on cumulative sum (CUSUM) and cumulative sum square (CUSUMSQ) tests are also reported in the next section. We also conducted robustness checks to confirm our findings; were performed dynamic ordinary least squares (DOLS) to estimate long-term elasticities of our independent variables, as well as Toda and Yamamoto non-Granger causality (TY) to investigate the direction of causality between variables.

4. Results and Discussion

This section gives a detailed interpretation and discussion of summary statistics, cointegration results, ARDL short-term and long-term estimates, diagnostic tests, and robustness checks in the form of DOLS and Toda and Yamamoto (TY) causality results.

4.1. Summary Statistics

The descriptive results provide pertinent information about the trends and patterns of variables. Table 5 reports descriptive statistics using both original values and the natural logarithmic conversion of variables. The average value of CO_2 emissions in Pakistan was 0.643 metric tons per capita with a standard deviation of 0.22 metric tons per capita ranging from 0.309 to 0.991 over the period 1971–2014. People in Pakistan consumed approximately 405.11 energy (kg of oil equivalent units) to meet their daily residential, commercial, and industrial demands. The income level per person amounted to roughly 764.21 (on average) dollars per year over the period. However, this GDP per capita varied greatly by around 220.45 dollars per annum, which connotes substantial income inequality in Pakistan. The service sector saw marvelous growth in Pakistan as compared to the agriculture and manufacturing sectors; it contributed 45.44% of the total value addition to GDP. The major chunk of the service sector aroused our interest; thus, we investigated its impact on emissions in Pakistan and whether it induced an inverted U-shaped nexus between income and pollution.

Table 5. Descriptive results.

Variables		Mean	Median	Max	Min	SD
Original Values	CO_2	0.643	0.654	0.991	0.309	0.220
	E	405.108	416.830	523.764	285.178	76.908
	Y	764.208	791.208	1111.196	453.791	202.447
	S	45.444	44.818	53.110	37.420	4.449
	T	33.219	33.392	38.909	19.932	3.492
Natural Log Transformation	$\ln CO_2$	−0.441	−0.425	−0.009	−1.176	−1.514
	lnE	6.004	6.033	6.261	5.653	4.343
	lnY	6.639	6.674	7.013	6.118	5.310
	lnS	3.816	3.803	3.972	3.622	1.493
	lnT	3.503	3.508	3.661	2.992	1.250

Note: CO_2 indicates CO_2 emissions per capita; E is the energy consumption in terms of kg of oil equivalent per capita; Y represents economic growth in terms of GDP per capita; S stands for the value added of services as a percentage of GDP; T denotes trade openness measures as a trade percentage of GDP; SD represents standard deviation; Max and Min represent maximum and minimum values.

4.2. Cointegration Results

Before investigating the short-term and long-term dynamics of ARDL approach, it is necessary to determine the cointegration relationship using a bounds testing procedure. Table 6 exhibits the cointegration estimates of our baseline models as stated in Equations (3) and (4). We present the cointegration results of four models, namely, the model without structural breaks, the model with structural breaks, the model of services' non-linearity and the model relating to non-linearity of energy consumption in Table 6. The bounds testing approach required the maximum number of lags, pertaining to variables, which was determined using a vector autoregressive (VAR) approach under the Schwarz-Bayesian criterion (SBC). The results of lag length are given in Table A1 (Appendix B). All four models indicated a cointegration relationship among air pollution, energy use, income level, quadratic term of income level, services, quadratic term of services (in the case of model 3), quadratic term of energy consumption (in the case of model 4), and trade openness, as the calculated F-values of the bound test were greater than the critical value at the 1% level of significance.

Table 6. Autoregressive distributive lag (ARDL) bound test for cointegrating relation.

Estimated Model	F-Stat	Lags (k)	Cointegration
Model 1: [lnCO_2/lnE, lnY, lnY^2, lnS, lnT]	17.631	(1,0,0,0,1,0)	Yes
Model 2: [lnCO_2/lnE, lnY, lnY^2, lnS, lnT, D80, D90]	13.089	(1,0,0,0,1,0,0,0)	Yes
Model 3: [lnCO_2/lnE, lnY, lnS, lnS^2, lnT]	10.506	(1,0,1,1,0,0)	Yes
Model 4: [lnCO_2/lnE, lnE^2, lnY, lnS, lnT]	13.311	(1.0,0,1,1,0)	Yes
Critical Values	LCB I(0)	LCB I(1)	
10% level	2.030	3.130	
5% level	2.320	3.500	
1% level	2.960	4.260	

Note: *, **, and *** indicate the 10%, 5%, and 1% levels of significance.

4.3. ARDL Long-Term and Short-Term Results

After establishing cointegration among our variables, the next step was to determine the short-term and long-term estimates of the ARDL model, as shown in Table 7. The table reports the results of four models. The first model reports the results of ARDL without structural break analysis. The second model incorporates the structural breaks in the ARDL model to compare the results with our first model. The third model exhibits the non-linear nexus between the services and environmental degradation to investigate the pollution reduction role of the service sector. The fourth and last model shows an inverted U effect of energy use on carbon emissions. Firstly, the long-term results are elaborated on below, along with their discussion.

The energy use had a positive and significant effect upon CO_2 emissions in all four models. For instance, the long-term elasticity of energy use indicated that a 1% increase in energy consumption led to 1.120%, 1.072%, and 1.226% increases in CO_2 emissions in all three cases. However, the quadratic term of energy uses in model 4 revealed very interesting results. The negative significant coefficient of the squared term of energy use indicated that that the linkage between energy use and carbon emissions loosened in the long run due to the adoption of more energy-efficient technologies and alternative sources of cleaner energy. These findings indicated that energy consumption had a positive effect on emissions during the early phase of economic growth due to increased fossil-fuel consumption. These results are in line with previous studies. For example, Zaman et al. [28] reported the pollution enhancing role of energy use for 90 countries, and Ozturk et al. [36] evidenced the positive effect of energy use on pollution in the case of Cambodia. However, during the latter stage of economic development and a structural shift to the service sector, the effect of energy consumption on pollution became negative due to the adoption of efficient technologies and renewable energy use. These findings are in line with Akram et al. [69], who documented the pollution mitigating role of energy efficiency and renewable energy in developing countries.

Table 7. Short-term and long-term results of ARDL model.

Long-Run				Short-Run			
Variables	**Coefficients**	**SE**	***p*-Values**	**Variables**	**Coefficients**	**SE**	***p*-Values**
Model 1: Non-linearity of GDP (without structural break analysis)							
lnE	1.120 ***	0.100	(0.000)	D (lnE)	0.984 ***	0.106	(0.000)
lnY	4.699 ***	0.853	(0.000)	D (lnY)	4.128 ***	0.694	(0.000)
lnY^2	−0.326 ***	0.065	(0.001)	D (lnY^2)	−0.287 ***	0.052	(0.000)
lnS	0.478 ***	0.136	(0.000)	D (lnS)	0.149	0.147	(0.317)
lnT	0.094 *	0.047	(0.052)	D (lnT)	0.082 **	0.040	(0.047)
α_0	−26.128 ***	2.851	(0.000)	ECT (−1)	−0.879 ***	0.094	(0.000)
Model 2: Non-linearity of GDP (with structural break analysis)							
lnE	1.072 ***	0.089	(0.000)	D (lnE)	0.935 ***	0.095	(0.000)
lnY	4.732 ***	0.795	(0.000)	D (lnY)	4.130 ***	0.625	(0.000)
lnY^2	−0.325 ***	0.061	(0.000)	D (lnY^2)	−0.283 ***	0.048	(0.000)
lnS	0.444 ***	0.118	(0.001)	D (lnS)	0.248 *	0.139	(0.082)
LnT	0.036	0.023	(0.135)	D (lnT)	0.031	0.021	(0.137)
D80	0.039 *	0.021	(0.073)	D80	0.034 *	0.018	(0.066)
D90	0.053 **	0.020	(0.012)	D90	0.046 **	0.017	(0.010)
α_0	−25.809 ***	2.715	(0.000)	ECT (−1)	−0.873 ***	0.053	(0.000)
Model 3: Non-linearity of services							
lnE	1.226 ***	0.144	(0.000)	D (lnE)	0.952 ***	0.131	(0.000)
lnY	0.320 *	0.138	(0.026)	D (lnY)	0.551 ***	0.194	(0.008)
lnS	14.734 ***	5.006	(0.006)	D (lnS)	11.188 ***	3.425	(0.003)
lnS^2	−1.862 ***	0.643	(0.007)	D (lnS^2)	−1.447 ***	0.441	(0.002)
LnT	0.169 *	0.065	(0.014)	D (lnT)	0.131 **	0.046	(0.007)
α_0	−39.640 ***	9.526	(0.000)	ECT (−1)	−0.777 ***	0.089	(0.000)
Model 4: Non-linearity of energy consumption							
lnE	10.892 ***	2.547	(0.000)	D (lnE)	8.592 ***	1.731	(0.000)
lnE^2	−0.796 ***	0.210	(0.001)	D (lnE^2)	−0.628 ***	0.145	(0.000)
lnY	0.162	0.139	(0.251)	D (lnY)	0.518 ***	0.179	(0.007)
lnS	0.622 ***	0.194	(0.003)	D (lnS)	0.199	0.167	(0.243)
LnT	0.124 **	0.059	(0.043)	D (lnT)	0.098 **	0.044	(0.033)
α_0	−41.040 ***	7.673	(0.000)	ECT (−1)	−0.789 ***	0.081	(0.000)
Diagnostic statistics							
	Model 1	Model 2	Model 3	Model 4			
Adjusted R^2	0.997	0.998	0.996	0.997			
F-Statistic	2606.277 [0.000]	2722.429 [0.000]	1627.441 [0.000]	1922.159 [0.000]			
BG LM χ^2	4.663 [0.097]	4.546 [0.103]	1.710 [0.425]	3.256 [0.196]			
BPG χ^2	11.940 [0.103]	8.929 [0.443]	4.889 [0.769]	10.002 [0.2649]			
JB Normality	0.233 [0.890]	0.214 [0.898]	0.267 [0.875]	0.540 [0.763]			
χ^2 Reset	1.678 [0.103]	1.215 [0.279]	1.502 [0.147]	1.532 [0.135]			

Note: *, **, and *** indicate 10%, 5%, and 1% levels of significance; *p*-values are reported in parentheses in the case of diagnostic tests; SE indicates standard errors; R^2 indicates the R-squared value; BG LM χ^2 is the Breusch-Godfrey serial correlation test (H_o: there is no serial correlation); BPG χ^2 indicates the Breusch-Pagan-Godfrey test for heteroscedasticity (H_o: data are homogeneous); JB is the Jarque-Berra normality test (H_o: data are normal); χ^2 Reset is the Ramsey specification test model (H_o: functional form is correct); α_0 is the intercept of the ARDL model; ECT(−1) is the error correction term representing the speed of adjustment to long-term equilibrium; D80 and D90 are dummy variables for the years 1980 and 1990, respectively.

The coefficient of income level implied a significant and positive impact on emissions in three cases. The income level (lnY) increased environmental degradation, and its long-term elasticity with respect to CO_2 emissions signified that a 1% increase in income level, as measured by GDP per capita, caused 4.699% and 4.732% tremendous increases in air pollution in model 1 and model 2, respectively, which had a highly elastic impact on environmental quality at the early stage of economic development in Pakistan. The quadratic term of income ($\ln Y^2$) was used to measure the EKC hypothesis in Pakistan. The negative and significant effect of $\ln Y^2$ on environmental quality in model 1 and model 2 confirmed the inverted U-shaped relationship between income level and pollution in Pakistan. Our findings indicated that economic development increased environmental degradation to a certain level, after which the higher level of income improved environmental quality. The elasticity of $\ln Y^2$ showed that a 1% increase in the quadratic term of income level lowered emissions by −0.326% and −0.325% in model 1 and model 2, respectively, investigating the non-linear nexus between income level and pollution. Our findings on the EKC curve are consistent with Gokmenoglu et al. [42], who also evidenced an inverted U-shaped relationship for the agriculture sector, as well as Usman et al. [13], who confirmed the EKC hypothesis in the case of India, and Zhang et al. [14], who evidenced this relationship for newly industrialized countries. Based on our EKC results, we could safely argue that the higher level of income raised more concerns for environmental protection in Pakistan as people could possibly be demanding a more sustainable environment. However, our results are contrary to Alshehry et al. [33], who failed to support an EKC for the transport sector in Saudi Arabia. The comparison of model 1 and model 2 indicated that our results were not much influenced by the inclusion of structural break analysis, and the EKC hypothesis was confirmed in both cases, which enhanced the validity and accuracy of our ARDL results. Moreover, the structural analysis given in the Table A2 (Appendix B) also confirmed the EKC hypothesis. We also ran other sets of year dummies of structural break years such as 1980 and 1993, as identified by ZA structural break tests, but our results were robust to our baseline models. These results are reported in Table A2 (Appendix B) for comparison. Our findings were quite robust to alternative specifications, and they confirmed the existence of the EKC hypothesis in Pakistan.

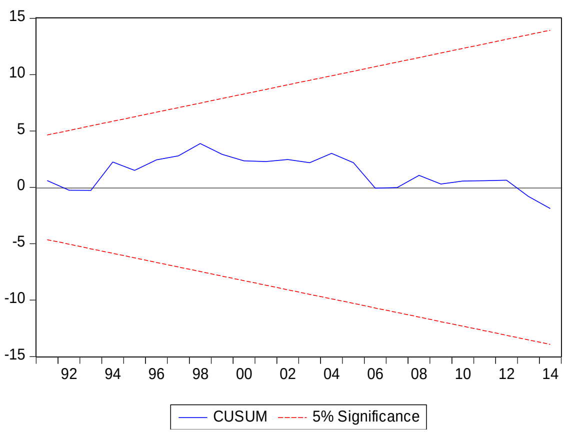
Model 3 also confirmed our previous findings, as it investigated the non-linear effect of services on CO_2 emissions. The economic growth had a positive and significant effect on pollution. However, the magnitude of this environmental damaging effect of income level became inelastic and substantially decreased due to the inclusion of the quadratic term of services. Initially, the growth in the service sector positively influenced air pollution in Pakistan. However, the negative coefficient of the squared term of services clearly indicated the pollution mitigating role at the later stage of development with a major structural shift to the service sector, which is a common phenomenon in developing countries. Therefore, our findings implied that the service sector induced an inverted U-shaped relationship between income level and pollution. There was tremendous growth of the service sector in Pakistan as compared to the agriculture and manufacturing sectors. The service sector, especially the transport sector, in Pakistan was the major source of fossil-fuel consumption in Pakistan. However, in the long term, the service sector played a positive role in reducing pollution in Pakistan because of the development of other sub-sectors of services such as educational institutes, the financial sector, healthcare institutions, retailing and wholesaling sectors, professional and personal services, government bodies, media, and the recreational sector; these sub-systems of the service sector caused a lesser amount of CO_2 emissions as compared to the industrial sector in Pakistan. Our findings conform to those of Zaman et al. [28], who evidenced the pollution reduction role of services in industrialized countries. On the other hand, our findings contradict those of Sohag et al. [1], who investigated the positive linear effect of services on CO_2 emissions in middle-income countries.

The effect of trade openness on environmental degradation was positive and significant in both the short term and the long term in models 1, 3, and 4. The findings indicated that trade openness did influence air pollution in Pakistan. Our results are consistent with prior studies of [10] in the case of Kenya and Khan et al. [38] in the case of Pakistan. In the long run, trade openness enhanced environmental degradation in Pakistan. Lastly, the dummy variables for structural breaks had a positive significant effect on CO_2 emissions due to the spread of the Afghan war in 1979 and structural and economic reforms in the 1990s. These structural changes had a worsening effect on environmental quality due to privatization and growth-enhancing policies in Pakistan. However, the elasticities of such environmental damage due to structural changes in 1980s and 1990s were very low, because a 1%

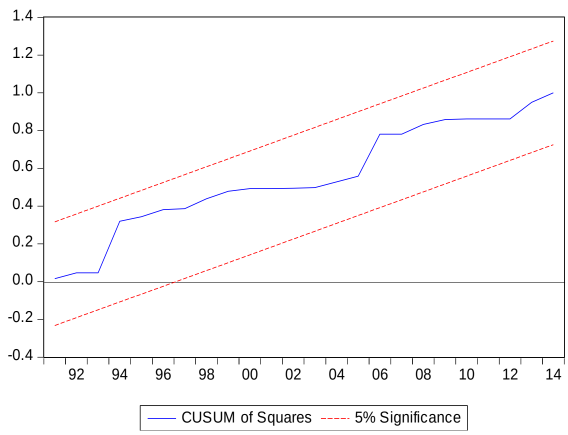
increase in economic reforms led to only 0.039% and 0.053 % increases in pollution at the 10% and 5% critical levels, respectively, which is not an alarming sign as far as the aftermath of the Afghan war, trade liberalization, and growth-inducing policies of the government are concerned.

The short-term results are also reported in Table 6 to measure any temporal fluctuations in independent variables and their possible impact on pollution. Energy use had a positive and significant coefficient, which indicated the emission enhancing role of energy consumption in Pakistan. The inverted U-shaped relationship between economic development and environmental degradation was also confirmed in the short term. The elasticities of income and its quadratic term were very much similar to the long-term elasticities. The inverted U-shaped relationship between services and pollution was also confirmed in the short term, which indicated that services improved the environmental quality in Pakistan in both the short term and the long term. In the short term, energy use also held an inverted U-shaped effect on pollution in model 4, which indicated energy efficiency and the use of cleaner energy. The dummy variables of structural breaks had a significant and positive effect on emissions in the short term, and they produced almost similar findings to those reported in the long-term case of the ARDL approach. Since the error correction term, ECT (−1), was negative and highly significant, this suggested that short-term fluctuations in our variables quickly converged to the long-term equilibrium by 87.9%, 87.3%, 77.7%, and 78.9% in a year in the case of all four models, making our long-term estimates very stable and predictable. The diagnostic tests are also reported in Table 7 to analyze the econometric problems associated with the model. The results indicated that the ARDL model in all four cases was not affected by the issues of autocorrelation, model stability, heteroscedasticity, and data normality in all three models. Since the χ^2 value of the Breusch-Godfrey test was insignificant, the null hypothesis of no autocorrelation was accepted.

The issue of heteroscedasticity also did not exist in our variables because the χ^2 value of the Breusch-Pagan-Godfrey test was insignificant, which did not refute the null hypothesis of homoscedasticity. Similarly, the Jarque-Berra (JB) normality test reported an insignificant value, which indicated that our data were normally distributed. The Ramsey reset test also indicated that the ARDL model was stable, which was further supported by our CUSUM and CUSUMSQ stability graphs in the case of model 2, as shown in Figure 2. Both graphs indicated that the ARDL model was stable, as the blue line of CUSUM and CUSUMSQ lay within 5% critical bounds. Similar results were produced for model 1 and model 3, but they are not shown here for the sake of brevity. The diagnostic tests indicated that all three ARDL models were not affected by econometric issues, which further validated our mainstream findings.



(**a**)



(**b**)

Figure 2. (**a**) CUSUM and (**b**) CUSUMSQ stability graphs in the case of model 2.

4.4. Alternative Specification for Robustness

We also applied alternative models as robustness measures to confirm our ARDL results, as discussed earlier. These robustness tests included fully modified ordinary least squares (FMOLS), dynamic ordinary least squares (DOLS), and the non-Granger causality test of Toda and Yamamoto (TY), which supported the results of our baseline model.

4.4.1. Results of FMOLS and Dynamic OLS (DOLS) and Discussion

After confirming the short-term and long-term effects of our ARDL model in the previous section, we applied fully modified OLS developed by Hansen et al. [82] and the dynamic OLS model developed by Stock et al. [83] to estimate the long-term effects of the service-induced EKC model. FMOLS is widely used as a robustness check after establishing a cointegration relationship among variables. It provides reliable estimates even in the case of small samples, while mitigating the econometric issues of serial correlation and endogeneity [84]. DOLS is another efficient, robust, and powerful modeling technique, which provides several benefits for empirical investigation. The DOLS estimator is widely used and practically convenient to provide robust findings in the case of small samples as compared to alternative specifications, while it does not require pre-testing of the unit root, aptly used in mixed and higher orders of integration. Moreover, it also addresses the issues of serial correlation and simultaneity or endogeneity bias [65,68,85,86]. Esteve et al. [87] argued that DOLS resolves the problem of a low power of classical cointegration tests, which makes it superior to other alternative options available for long-term effects.

We provide long-term estimates of FMOLS and DOLS in Table 8 which support our previous results and findings of the ARDL approach, and the signs of coefficients did not alter as predicted by the ARDL model. Moreover, the degrees of long-term elasticities also fell within a similar range to that shown in Table 7, making our results reliable and predictable for policy formulation and implementation. Energy consumption had a positive and significant effect on CO_2 in all three models, which implied that the higher use of energy resources created more pollution in Pakistan. However, when we applied the quadratic term of energy use in model 4, the coefficient of its squared term became negative and highly significant at the 1% level. Similar to the ARDL model, these findings confirmed an inverted U-shaped effect of energy consumption and emissions. The bell-shaped relationship connoted that energy consumption had a positive effect on environmental degradation during the early stage of economic development because of certain energy inefficiencies, which demanded energy conservative strategies to find alternative and renewable sources of energy. These finding are also supported by Ali et al. [18] in the case of Malaysia and for OECD countries. However, at the later stage of economic progression, the energy use reduced environmental degradation due to energy-efficient technologies and the use of renewable energy production, which loosened the physical link between energy consumption and carbon emissions. The coefficients of income level and its respective quadratic term predicted the accurate signs of positive and negative effects on environmental degradation, and they verified the inverted U-shaped relationship between income level and pollution. These findings indicated that the EKC hypothesis holds in Pakistan. However, the magnitude of $\ln Y^2$ was lower than $\ln Y$, which indicated that awareness about environmental issues and reducing the income inequality are needed to address the environmental pressure in a beneficial manner. Our findings are aligned with previous findings which also confirmed a bell-shaped relationship between economic growth and pollution [38,40]. The rising income level of people in Pakistan over the years created more demand and preference for cleaner environment. However, the inelastic effect of the quadratic term of income level indicated that the responsiveness of CO_2 emissions to income level occurred slowly because of rising income inequality and poor urban planning in big cities, which led to greater challenges for Pakistan. The service sector had a positive and significant effect on emissions in Pakistan in the case of checking non-linearity of GDP. However, when the quadratic term of services was added to our baseline model, it showed an inverted U-shaped relationship between services and environmental degradation. These findings connoted that the major structural shift from the agriculture to the service sector resulted in a lower level of CO_2 emissions over the time. Our findings are consistent with the empirical work of Zaman et al. [28], who argued that the service sector reduces pollution in the world, while the manufacturing sector increases global emissions. Trade openness had a positive and significant effect on pollution in Pakistan. These results indicated that trade worsened the environmental quality, because the environmental protection policy did not seem to regulate the trade practices to account for environmental concerns in the country. Our results are also supported by the empirical work of Danish et al. [88], who documented the positive effect of trade on pollution in the case of BRICS (Brazil, Russia, India, China, and South Africa) economies.

Table 8. Estimating long-run elasticities using fully modified ordinary least squares (FMOLS) and dynamic ordinary least squares (DOLS).

	FMOLS			**DOLS**		
Variables	**Coefficients**	**SE**	***p*-Value**	**Coefficients**	**SE**	***p*-Value**
Non-linearity of income level (EKC curve)						
lnE	0.985 ***	0.087	(0.000)	1.082 ***	0.089	(0.000)
lnY	4.424 ***	0.540	(0.000)	5.837 ***	0.704	(0.000)
$\ln Y^2$	−0.309 ***	0.040	(0.000)	−0.415 ***	0.055	(0.000)
lnS	0.207 **	0.097	(0.040)	0.697 **	0.150	(0.044)
LnT	0.082 ***	0.026	(0.004)	0.122 ***	0.057	(0.000)
α_0	−24.028 ***	2.166	(0.000)	−30.509 ***	2.434	(0.000)
Adjusted R^2	0.997			0.997		
SE of regression	0.019			0.019	0.018	
Long-term variance	0.000			0.000	0.000	
Non-linearity of services (augmented EKC)						
lnE	0.870 ***	0.139	(0.000)	1.157 ***	0.116	(0.000)
lnY	0.633 ***	0.168	(0.001)	0.250 **	0.116	(0.044)
lnS	11.760 ***	3.386	(0.002)	30.327 ***	4.822	(0.000)
$\ln S^2$	−1.512 ***	0.437	(0.002)	−3.847 ***	0.616	(0.000)
LnT	0.143 ***	0.040	(0.001)	0.249 ***	0.067	(0.001)
α_0	−30.857 ***	6.904	(0.000)	−69.625 ***	9.243	(0.000)
Adjusted R^2	0.996					
SE of regression	0.022					
Long-term variance	0.000					
Non-linearity of energy consumption (augmented EKC)						
lnE	8.870 ***	1.510	(0.000)	14.140 ***	2.435	(0.000)
$\ln E^2$	−0.653 ***	0.123	(0.000)	−1.069 ***	0.201	(0.000)
lnY	0.583 ***	0.129	(0.000)	0.095	0.145	(0.519)
lnS	0.267 **	0.120	(0.033)	0.891 ***	0.240	(0.001)
LnT	0.108 ***	0.032	(0.002)	0.172 **	0.076	(0.034)
α_0	−32.989 ***	4.905	(0.000)	−51.441 ***	7.415	(0.000)
Adjusted R^2	0.997					
SE of regression	0.020					
Long-term variance	0.000					

Note: *, **, and *** indicate 10%, 5%, and 1% levels of significance; SE indicates standard errors; α_0 is the constant term of FMOLS and DOLS; EKC is the environmental Kuznets curve.

4.4.2. Toda and Yamamoto Non-Granger Causality Results

After confirming our ARDL results with dynamic OLS and estimating long-term effects, the next step was to investigate the causality of our variables in at least one direction. The causality results provided further support to our previous findings, and they can help in policy making. Since our variables had a mixed order of cointegration, we applied the Toda and Yamamoto (TY) test, which is a non-Granger causality approach to explore unidirectional or feedback relationships between energy consumption, income level and its quadratic term, services, and trade openness with CO_2

emissions in Pakistan. TY causality can be applied even when variables are integrated at level I(0), first difference (I(1)) or higher order (I(n)), or even nonintegrated [89]. Moreover, the TY approach controls for econometric issues related to unit root and various cointegration approaches, because it does not require the desired order of integration and long-term cointegration [30,42,90]. This approach is compatible with our ARDL model because our variables were integrated at I(0) and I(1).

The Toda and Yamamoto causality approach summed up the maxim integration order of variables (k) and optimal lag length (d_{max}) of variables determined under the VAR approach. Since our variables were integrated at I(1) and the optimal leg length was also 1, the maximum lag length 2 (k + d_{max}) was applied to investigate causal interactions between our variables. The modified Wald test (MWALD), as suggested by Toda et al. [89], was used to determine the significance of causal linkages. The basic equation of TY can be stated as follows:

$$\begin{aligned} LnCO_{2t} = {} & \alpha_o + \sum_{i=1}^{k} \delta_{1i} LnCO_{2t-i} + \sum_{i=k+1}^{d_{max}} \delta_{2j} LnCO_{2t-j} + \sum_{i=1}^{k} f_{1i} LnE_{t-i} + \sum_{i=k+1}^{d_{max}} f_{2j} LnE_{t-j} \\ & + \sum_{i=1}^{k} J_{1i} LnY_{t-i} + \sum_{i=k+1}^{d_{max}} J_{2j} LnY_{t-j} + \sum_{i=1}^{k} J_{1i} LnY^2{}_{t-i} + \sum_{i=k+1}^{d_{max}} J_{2j} LnY^2{}_{t-j} \\ & + \sum_{i=1}^{k} f_{1i} LnS_{t-i} + \sum_{i=k+1}^{d_{max}} f_{2j} LnS_{t-j} + \sum_{i=1}^{k} \sigma_{1i} LnT_{t-i} + \sum_{i=k+1}^{d_{max}} \sigma_{2j} LnT_{t-j} + \varepsilon_{1t} \end{aligned} \tag{7}$$

Similar causality equations could be formulated by taking each independent variable on the left-hand side (LHS). These remaining causality equations are given in Appendix C. We report the causality results in Table 9 using the TY causality approach. The results indicated that unidirectional causality existed between energy consumption and CO_2 emissions. Energy consumption caused environmental degradation in Pakistan, which is not a healthy sign for sustainable development. Our results are congruent to the findings of Khan et al. [38], who investigated unidirectional causality between energy use and pollution in the case of Pakistan. There existed a bidirectional or feedback causal relationship between income level and its quadratic term and CO_2 emissions, which confirmed the EKC hypothesis in Pakistan. The findings indicated that income level and environmental degradation were interlinked and affected each other. Our findings are compatible with those of Kisswani et al. [19], who found bidirectional causality for Thailand and Malaysia, and Gokmenoglu et al. [42] in the case of Pakistan. However, CO_2 emissions affected income level at the 10% level of significance, which showed a weak effect, suggesting that a more stringent environmental policy is required to improve the environment. These findings were also supported by the inelastic behavior of quadratic term of income level, which demands more serious efforts for improving the environmental quality in Pakistan.

Table 9. The results of Toda and Yamamoto (TY) causality test.

No.	Hypothesis	Chi-Square	*p*-Value	Decision
1	lnE does not cause $lnCO_2$	10.783 **	0.029	Reject
2	$lnCO_2$ does not cause lnE	6.135	0.189	Accept
3	lnY does not cause $lnCO_2$	10.348 **	0.035	Reject
4	$lnCO_2$ does not cause lnY	7.836 *	0.098	Reject
5	lnY^2 does not cause $lnCO_2$	10.094 **	0.039	Reject
6	$lnCO_2$ does not cause lnY^2	7.931 *	0.094	Reject
7	lnS does not cause $lnCO_2$	5.449 *	0.066	Reject
8	$lnCO_2$ does not cause lnS	2.114	0.347	Accept
9	lnS^2 does not cause $lnCO_2$	5.670 *	0.058	Reject
10	$lnCO_2$ does not cause lnS^2	2.033	0.362	Accept
11	lnT does not cause $lnCO_2$	6.833	0.145	Accept
12	$lnCO_2$ does not cause lnT	3.073	0.546	Accept

Note: *, **, and *** indicate 10%, 5%, and 1% levels of significance.

There existed a unidirectional causal relationship between services and CO_2 emissions. Since the service sector is considered to be less energy-intensive, the major shift from the agriculture sector to the service sector reduced the environmental degradation over the time. The TY causality test also indicated that trade openness did not cause pollution, as evidenced by the results of ARDL and DOLS in the previous section.

5. Conclusions and Policy Implications

This study investigated the long-term relationships among energy consumption, income level, services, trade openness, and CO_2 emissions in Pakistan over the time period 1971–2014 using ARDL with structural break analysis; we also applied DOLS and Toda-Yamamoto causality tests as robustness measures to confirm the findings of the baseline model. Our pioneer research confirmed the role of the service sector in inducing the EKC hypothesis in Pakistan. Our findings confirmed the inverted U-shaped relationship between income level and environmental degradation as measured by CO_2 emissions. Income level caused pollution at the initial stage of economic development; however, after reaching a certain threshold, it tended to decline environmental degradation. The service sector exhibited an inverted U-shaped nexus with CO_2 emissions. Moreover, energy consumption had a bell-shaped effect on carbon emissions in Pakistan, which resulted in certain energy efficiency measures and cleaner energy production. The application of the DOLS model, as an alternative specification, confirmed the findings of ARDL and supported the EKC hypothesis along with a U-shaped effect of services and energy consumption on environmental degradation. The results of the Toda and Yamamoto test indicated the unidirectional causality between energy consumption and pollution, and the feedback relationship between income level and the service sector and CO_2 emissions. However, we did not find any causal relationship between trade openness and pollution in the case of Pakistan.

The current study verified the existence of an EKC in Pakistan, and these findings are similar to previous studies of Kisswani et al. [19] for Thailand and Usman et al. [13] in the case of India, conducted in developing countries. Although our results confirmed the existence of an inverted U-shaped relationship between economic development and air pollution, the improvement in environmental quality had a very sluggish behavior after the turning point of the EKC. The government should not only accelerate the real economic growth, address the issues of hyperinflation and unemployment in the country, and implement social inclusion strategies to reduce income inequality; they should also initiate environmental awareness and protection campaigns to escalate the mitigating process of environmental damage. The bidirectional causality between income level and CO_2 emissions also connoted that any effort to reduce CO_2 emissions will occur at the cost of economic development because both variables are linked.

The growth of the service sector induced the EKC hypothesis in Pakistan because of a shift from manufacturing to services over the last few decades. Moreover, the inelastic effect of services on environmental degradation in the case of models 1 and 2 is not an alarming sign in the short term. The non-linearity of services was also tested using ARDL and robustness analysis, which exhibited an inverted U-shaped effect of services on CO_2 emissions. The tremendous growth of the service sector and the development of less energy-intensive sub-systems of services such as the educational sector, financial institutions, retailing and wholesaling sectors, personal and professional services, government services, and the recreational industry reduced pollution in the country. This phenomenon was further supported by the existence of a bell-shaped effect of energy consumption on carbon emissions, as tested in our previous section of results. These findings indicated that there was a tight linkage between energy consumption and pollution in the early phase of economic development and industrial growth, causing environmental degradation at a higher rate. However, during the later phase of economic development and the structural shift to the service sector, this link loosened due to energy-efficient technologies and the adoption of renewable energy resources in Pakistan.

Our research findings have significant and vital implications for designing appropriate environmental policies to mitigate environmental degradation. Although our findings verified the pollution mitigating role of energy use in Pakistan, the impact was relatively inelastic, and further efforts are required by the government to adopt energy conservation and optimization policies as implemented in other developing countries. According to World Bank Development Indicators (WDIs), Pakistan was reported to have consumed approximately 60% fossil-fuel energy consisting of oil, natural gas, petroleum, and coal. Thus, the Pakistan economy is still heavily dependent upon fossil-fuel energy, which is excreting substantial environmental pressure by emitting a huge amount of CO_2 emissions. Similar to energy conservation and cleaner production strategies adopted in China, the government should build new water reservoirs to produce electricity to meet the growing demand for household, commercial, and industrial consumption, they should also formulate and implement an energy conservative policy, as well as raise the share of renewable energy options such as solar, wind, hydropower, and biomass in the total energy mix. The government should invest more money in renewable energy projects to mitigate the issue of rising environmental degradation.

Although the overall impact of the service sector on environmental quality does not raise sustainability issues for Pakistan, the analysis of sub-systems of services is recommended for further investigation and policy formulation. For instance, some sub-sectors of the service sector also generate pollution in the long run because of their linkage with building infrastructure, transportation, and electric power generation. The rising population and urban development are also causing substantial demand for services such as transportation, electricity, and building materials. The transport and logistic systems are the major causes of direct CO_2 emissions because of the fossil-fuel energy used to meet this ever-increasing demand. There is an urgent need to improve the transportation system by introducing an efficient public transportation system and infrastructure to mitigate the issues of traffic congestion and air pollution, especially in the largest cities of Pakistan. The government should also design and implement an effective urban planning mechanism to introduce energy-efficient buildings such as skyscrapers and the idea of a compact city. The service sector also heavily depends upon industrial sectors for provision of its input, which could indirectly cause pollution. This input–output linkage between the service sector and other industries should be comprehended to design an all-inclusive pollution mitigating strategy for long-term consequences. Since the service sector also demands electricity consumption for running its operations, more options based on renewable energy for power generation should be explored and implemented to reduce the overall level of pollution in the country.

The current study investigated the issue of structural change in detail, but we recommend future researchers to also include other sectors of the economy, as well as perform decomposition analysis. We only used total energy consumption to measure energy efficiency by taking its quadratic term, but the unavailability of renewable energy data (data are available only from 1990 onward from the World Bank) for the sample period constrained us to making a comparative assessment. Moreover, the time series models such as ARDL and cointegration tests allowed a limited number of variables. Therefore, additional factors such as urbanization, population growth, and financial development could be utilized in future research.

Author Contributions: S.H.H. was responsible for conceptualization, writing-original draft, investigation, and methodology; F.H. was responsible for supervision; Z.F. collected the data for the research; R.B. conducted review and editing. All authors read and agreed to the published version of the manuscript.

Funding: This research was funded by National Social Science Foundation of China, grant number [17BJL108].

Conflicts of Interest: The authors declare no conflicts of interest.

Appendix A

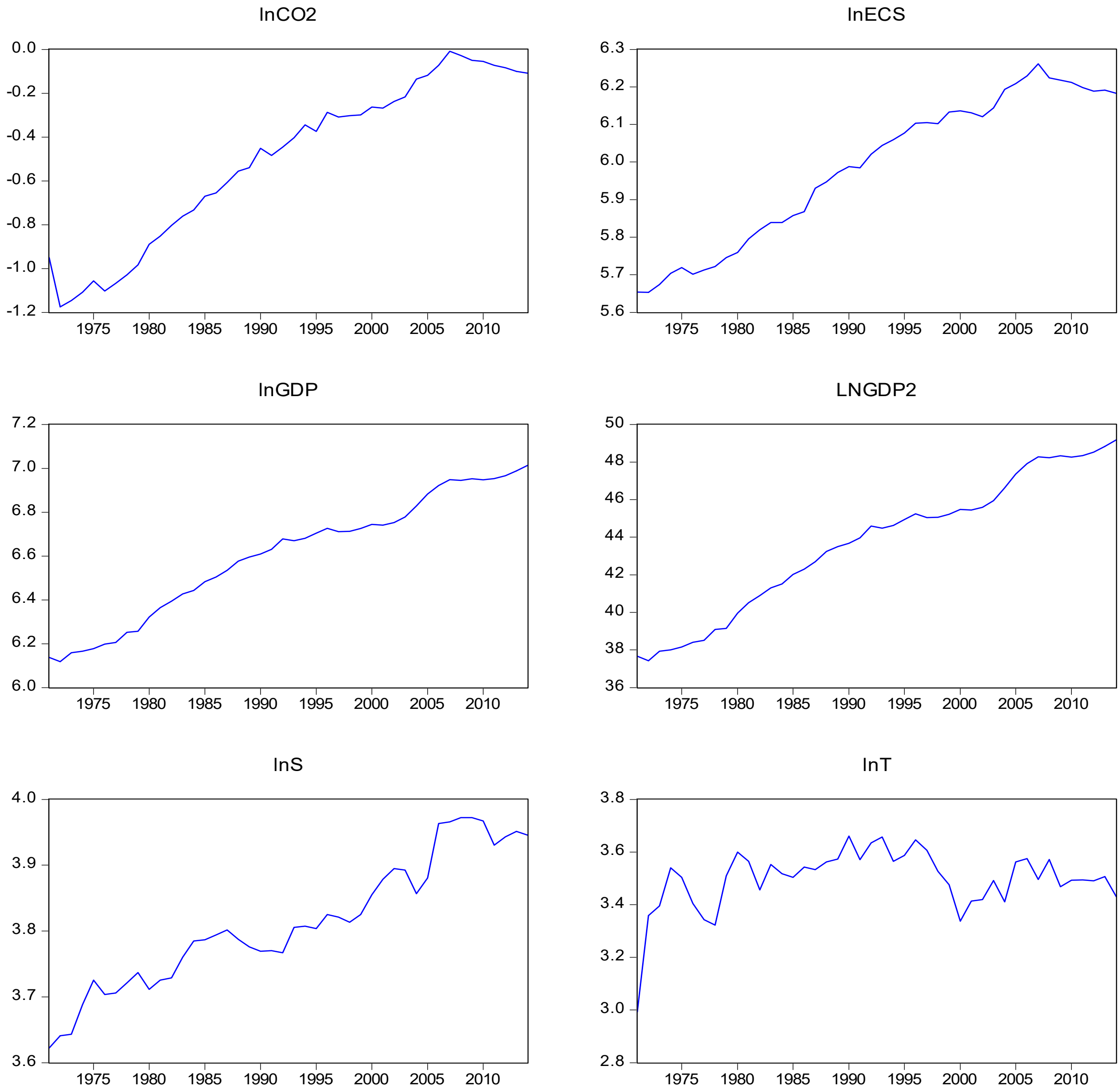


Figure A1. Time trends of variables over 1971–2014.

Appendix B

Table A1. Lag length determination.

Variable Name	Lag 0	Lag1	Lag 2	Lag 3	Lag 4
$\ln CO_2$	0.727	−3.775 *	−3.711	−3.671	−3.584
lnECS	−0.549	−5.008 *	−4.937	−4.846	−4.755
lnGDP	0.109	−5.094 *	−5.057	−4.977	−4.886
$\ln GDP^2$	5.272	0.079 *	0.104	0.188	0.276
lnSRV	−2.004	−4.709 *	−4.629	−4.647	−4.555
LnTOP	−2.041	−2.401 *	−2.209	−2.217	−2.135

Note: Lag lengths of variables were determined on the basis of the Schwarz information criterion (SC).

Table A2. Short-term and long-term results of ARDL model (structural analysis for years 1980 and 1993).

	Long Term				Short Term		
Variables	**Coefficients**	**SE**	***p*-Values**	**Variables**	**Coefficients**	**SE**	***p*-Values**
lnE	1.081 ***	0.096	(0.000)	D(ECS)	0.931 ***	0.101	(0.000)
lnY	4.919 ***	0.859	(0.000)	D(GDP)	4.240 ***	0.680	(0.000)
$\ln Y^2$	−0.339 ***	0.065	(0.000)	D(GDP2)	−0.292 ***	0.052	(0.000)
lnS	0.410 ***	0.127	(0.003)	D(SRV)	0.353 ***	0.104	(0.002)
LnT	0.060	0.046	(0.205)	D(TOP)	0.052	0.039	(0.200)
D80	0.041 *	0.022	(0.071)	D80	0.036 *	0.019	(0.065)
D93	0.024	0.031	(0.446)	D93	−0.009	0.019	(0.623)
C	−26.435 ***	2.880	(0.000)	ECT(−1)	−0.862 ***	0.057	(0.000)
Diagnostic statistics							
R^2	0.998						
Adjusted R^2	0.997						
F-Statistic	2098.538 [0.000]						
BG LM χ^2	2.203 [0.332]						
BPG χ^2	7.753 [0.559]						
JB Normality	1.382 [0.501]						
ARDL Bound Test	12.942 [2.96, 4.26]						
χ^2 Reset	1.730 [0.198]						

Note: *, **, and *** indicate 10%, 5%, and 1% levels of significance; *p*-values are reported in parentheses in the case of diagnostic tests; SE indicates standard errors; R^2 indicates the R-squared value; BG LM χ^2 is the Breusch-Godfrey serial correlation test; BPG χ^2 indicates the Breusch-Pagan-Godfrey Test for heteroscedasticity; JB is the Jarque-Berra normality test; χ^2 Reset is the Ramsey model stability test; ECT(−1) is the error correction term representing the speed of adjustment to long-term equilibrium; D80 and D93 are dummy variables for the years 1980 and 1993, respectively, representing break years.

Appendix C. Toda and Yamamoto Causality Equations

$$\begin{aligned} LnE_t = \alpha_o &+ \sum_{i=1}^{k} f_{1i} LnE_{t-i} + \sum_{i=k+1}^{d_{max}} f_{2j} LnE_{t-j} + \sum_{i=1}^{k} \delta_{1i} LnCO_{2t-i} + \sum_{i=k+1}^{d_{max}} \delta_{2j} LnCO_{2t-j} \\ &+ \sum_{i=1}^{k} J_{1i} LnY_{t-i} + \sum_{i=k+1}^{d_{max}} J_{2j} LnY_{t-j} + \sum_{i=1}^{k} J_{1i} LnY^2{}_{t-i} + \sum_{i=k+1}^{d_{max}} J_{2j} LnY^2{}_{t-j} \\ &+ \sum_{i=1}^{k} f_{1i} LnS_{t-i} + \sum_{i=k+1}^{d_{max}} f_{2j} LnS_{t-j} + \sum_{i=1}^{k} \sigma_{1i} LnT_{t-i} + \sum_{i=k+1}^{d_{max}} \sigma_{2j} LnT_{t-j} + \varepsilon_{1t} \end{aligned} \tag{A1}$$

$$\begin{aligned} LnY_t = \alpha_o &+ \sum_{i=1}^{k} J_{1i} LnY_{t-i} + \sum_{i=k+1}^{d_{max}} J_{2j} LnY_{t-j} + \sum_{i=1}^{k} f_{1i} LnE_{t-i} + \sum_{i=k+1}^{d_{max}} f_{2j} LnE_{t-j} \\ &+ \sum_{i=1}^{k} \delta_{1i} LnCO_{2t-i} + \sum_{i=k+1}^{d_{max}} \delta_{2j} LnCO_{2t-j} + \sum_{i=1}^{k} J_{1i} LnY^2{}_{t-i} + \sum_{i=k+1}^{d_{max}} J_{2j} LnY^2{}_{t-j} \\ &+ \sum_{i=1}^{k} f_{1i} LnS_{t-i} + \sum_{i=k+1}^{d_{max}} f_{2j} LnS_{t-j} + \sum_{i=1}^{k} \sigma_{1i} LnT_{t-i} + \sum_{i=k+1}^{d_{max}} \sigma_{2j} LnT_{t-j} + \varepsilon_{1t} \end{aligned} \tag{A2}$$

$$\begin{aligned} LnY^2{}_t = \alpha_o &+ \sum_{i=1}^{k} J_{1i} LnY^2{}_{t-i} + \sum_{i=k+1}^{d_{max}} J_{2j} LnY^2{}_{t-j} + \sum_{i=1}^{k} f_{1i} LnE_{t-i} + \sum_{i=k+1}^{d_{max}} f_{2j} LnE_{t-j} \\ &+ \sum_{i=1}^{k} \delta_{1i} LnCO_{2t-i} + \sum_{i=k+1}^{d_{max}} \delta_{2j} LnCO_{2t-j} + \sum_{i=1}^{k} J_{1i} LnY_{t-i} + \sum_{i=k+1}^{d_{max}} J_{2j} LnY_{t-j} \\ &+ \sum_{i=1}^{k} f_{1i} LnS_{t-i} + \sum_{i=k+1}^{d_{max}} f_{2j} LnS_{t-j} + \sum_{i=1}^{k} \sigma_{1i} LnT_{t-i} + \sum_{i=k+1}^{d_{max}} \sigma_{2j} LnT_{t-j} + \varepsilon_{1t} \end{aligned} \tag{A3}$$

$$\begin{aligned} LnS_t = \alpha_o &+ \sum_{i=1}^{k} J_{1i} LnS_{t-i} + \sum_{i=k+1}^{d_{max}} J_{2j} LnS_{t-j} \sum_{i=1}^{k} f_{1i} LnE_{t-i} + \sum_{i=k+1}^{d_{max}} f_{2j} LnE_{t-j} \\ &+ \sum_{i=1}^{k} \delta_{1i} LnCO_{2t-i} + \sum_{i=k+1}^{d_{max}} \delta_{2j} LnCO_{2t-j} + \sum_{i=1}^{k} J_{1i} LnY_{t-i} + \sum_{i=k+1}^{d_{max}} J_{2j} LnY_{t-j} \\ &+ \sum_{i=1}^{k} J_{1i} LnY^2{}_{t-i} + \sum_{i=k+1}^{d_{max}} J_{2j} LnY^2{}_{t-j} + \sum_{i=1}^{k} \sigma_{1i} LnT_{t-i} + \sum_{i=k+1}^{d_{max}} \sigma_{2j} LnT_{t-j} + \varepsilon_{1t} \end{aligned} \quad (A4)$$

$$\begin{aligned} LnT_t = \alpha_o &+ \sum_{i=1}^{k} J_{1i} LnT_{t-i} + \sum_{i=k+1}^{d_{max}} J_{2j} LnTOP_{t-j} \sum_{i=1}^{k} f_{1i} LnE_{t-i} + \sum_{i=k+1}^{d_{max}} f_{2j} LnE_{t-j} \\ &+ \sum_{i=1}^{k} \delta_{1i} LnCO_{2t-i} + \sum_{i=k+1}^{d_{max}} \delta_{2j} LnCO_{2t-j} + \sum_{i=1}^{k} J_{1i} LnY_{t-i} + \sum_{i=k+1}^{d_{max}} J_{2j} LnY_{t-j} \\ &+ \sum_{i=1}^{k} J_{1i} LnY^2{}_{t-i} + \sum_{i=k+1}^{d_{max}} J_{2j} LnY^2{}_{t-j} + \sum_{i=1}^{k} \sigma_{1i} LnS_{t-i} + \sum_{i=k+1}^{d_{max}} \sigma_{2j} LnS_{t-j} + \varepsilon_{1t} \end{aligned} \quad (A5)$$

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