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Revisiting the Environmental Kuznets Curve Hypothesis in South Asian Countries: The Role of Energy Consumption and Trade Openness

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Abstract: South Asian countries have seen remarkable economic growth and development in the past few decades. This has been driven by financial sector reforms, industrialization, and expansion of foreign trade. The present study is designed to identify the long- and short-run relationships among environmental degradation, economic growth, energy consumption, and trade openness in the South Asian region. Our research contributes to the literature by employing a new approach (the NARDL method). We examine annual data for four South Asian countries between 1971 and 2014. We found that there was a long-run equilibrium relationship between environmental degradation, economic growth, energy consumption, and trade openness. The results confirmed the inverted U-shaped EKC hypothesis only for India and Pakistan. However, the long-term coefficients related to energy consumption were statistically significant only in Pakistan. The most interesting finding was that only in Sri Lanka did the long-run coefficients associated with trade openness shocks significantly impact carbon dioxide emissions. These impacts were based on the scale effect. Our study has some policy implications. Foremost, the governments of South Asian countries should promote and subsidize green energy use by increasing R&D spending on renewable energy.

Keywords: environmental Kuznets curve; South Asian countries; trade openness; energy consumption; economic growth; carbon dioxide emissions; NARDL model; ARDL model



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1. Introduction

In the past few decades, South Asian countries have seen remarkable economic growth and development. This is attributable to financial sector reforms, industrialization, and expansion of foreign trade. The region's gross domestic product increased more than 17-fold—from 190.7 to 3241.9 billion US dollars from 1960 to 2020, with an average annual growth rate of 4.92%. It is noteworthy that this region's growth rate has been higher compared to the world's. Between 1961 and 1979, the world's growth rate was ahead of the growth rate of South Asian countries several times. However, this relationship changed from 1980 onwards, due to financial sector reform. In the early 1980s, financial sector reform, particularly banking sector reform, was initiated by South Asian countries to increase their competitiveness. As a result, policies have been adopted to restructure public sector banks and allow private sector banks to promote competition in the banking sector, and efforts have been taken to liberalize the financial sector [1]. Between 1980 and 2020, the South Asian region's growth rate was above the world's growth rate. Notably, only in 1984, 2000, and 2020 was the world's growth rate ahead of that of the South Asian region.

Although this region's growth performance is impressive, South Asia is globally perceived as an underprivileged region, where more than 50% of the world's poor live. To eliminate poverty and unemployment, the South Asian region supports fast economic

growth. This, however, is done without assessing the vulnerabilities of the environment [2]. The curtailment of energy consumption is not an easy task as it slows down the economic growth and development of a country [3].

Noteworthy, one of the necessary components of the economic growth of a country is trade openness and expansion in foreign trade, which enhances economic activities and energy demand [4]. Trade openness enables many underdeveloped or developing countries to import the latest technology from developed nations, which in turn helps them to produce more output while lowering energy intensity. Trade openness may simultaneously determine income and environmental quality. In South Asian countries, the volume of trade has shown an increasing trend since the early 1980s, which might be due to the financial sector reform in 1980. The merchandise trade, which is the combination of exports and imports, worth 6.6 billion US dollars in 1960, increased to 39.9 billion US dollars in 1980 and reached 1083 billion US dollars in 2018. At the same time, the total amount of CO₂ emissions increased from 0.26 to 1.53 metric tons per capita from 2006 to 2018. In 2018, South Asian countries exported 41% of manufactured products [5]. Trade openness leads to deterioration of the environmental quality due to large-scale production of merchandise goods, which causes higher energy consumption and CO₂ emissions.

Foreign trade expansion and industrialization results in a growing demand for energy consumption. For example, the total fossil fuel energy consumption in the South Asian region amounted to 33.87% in 1971 and more than doubled in 2014 to 71.52%. The consensus believes that the consumption of fossil fuels (coal, natural gas and oil) led to a rapid increase in CO₂ emissions, disrupting environmentally sustainable growth in South Asia. India, Bangladesh, Pakistan, and Sri Lanka consume more fossil fuel compared with other countries of that region. South Asia's percentage share of the world's fossil fuel consumption increased from 40 to 88% from 1971 to 2014.

Many studies have been conducted on the environmental Kuznets curve hypothesis in South Asian countries; for example, the recently published studies by Sadiq et al. [6], Ali et al. [7], Mehmood et al. [8], and Tan et al. [9]. However, the empirical results for those countries are mixed. Most researchers have used the conventional cointegration approaches. In this study, we make several contributions to the current literature. First, we used a method that does not ignore the asymmetry effect. Second, we consider the roles of energy consumption and asymmetric shocks in trade openness in the environmental Kuznets curve. Third, we describe how government programs could influence environmental quality, especially in India and Pakistan, where the long-run coefficient for squared GDP per capita is negative and significant. These coefficients indicate that we should expect increased environmental quality.

Our aim is to identify long-run and short-run relationships between environmental degradation, economic growth, energy consumption, and trade openness in South Asian countries. We examine annual data for four South Asian countries (India, Bangladesh, Sri Lanka, and Pakistan) for the period between 1971 and 2014. The selection of the time period and sample was determined by data availability. All annual time series data come from the World Bank collection of development indicators.

The remainder of the paper is structured as follows: Section 2 reviews literature on environmental degradation in South Asian countries and the linkages between energy consumption, trade openness, and carbon dioxide emissions; Section 3 describes the data and methodology; Section 4 presents the empirical results. In this section, we present both linear and non-linear ARDL models. Section 5 includes conclusions and highlights policy implications.

2. Literature Review

2.1. Environmental Degradation in South Asian Countries

The South Asian region faces large-scale environmental issues compounded by the overlapping factors of growing industrialization, urbanization, population growth, and increasing international trade [10]. In recent years, countries in South Asia have seen

growing urbanization and industrialization, which has led to rising rates of greenhouse gas emissions and increasing levels of environmental degradation [11,12].

This region has enjoyed some successes in reducing poverty. This was possible thanks to rapid industrialization and the implementation of liberal economic reforms. India and Bangladesh have been overly involved in expanding heavy industries due to their partial adoption of the development model. This has led to an increased industrial output and acceleration of environmental deterioration. According to Mehmood and Tariq [13], globalization led to an increase in CO₂ emissions in South Asian nations. This trend was observed from 1972 to 2013. It does not mean that rising production is always positively connected with environmental degradation indices; instead, environmental degradation depends on the use of contemporary technology and regulations adopted to protect the environment.

The International Energy Agency (IEA) predicted that during the next few decades, the demand for energy in the South Asian region would increase at a rate more than twice as fast as the average growth rate for the entire world. The rise in economic activity results in higher energy demand, contributing to the economy's expansion and growth. Rahman and Velayutham [14] examined the effect of consumption of renewable and non-renewable energy, and the effect of fixed capital formation on economic growth for a panel of five South Asian countries over the period of 1990–2014. Their findings indicated that these factors positively contributed to economic growth. In this scenario, increased economic activity may hasten the exhaustion of natural resources and lead to environmental deterioration in the absence of sufficient regulations. Greater consumption of resources results in a rise in carbon dioxide emissions and a decline in environmental quality, negatively influencing human health [8,15].

Increasing population growth, widespread poverty, lack of public awareness of environmental issues, failure to properly and robustly implement environmental laws and regulations, and failure to monitor environmental conditions—all these factors contribute to the deterioration of the environment. The vast majority of the unemployed in South Asia are low-skilled workers earning daily wages in the informal sector. One could argue that widespread poverty is the most significant contributor to the deterioration of the environment in this region. People who live below the poverty line are highly reliant on the services provided by ecosystem services, for their livelihoods [16]. They focus on satisfying their immediate needs rather than achieving future security regarding resources. People are driven to desperate measures by lack of financial resources. As a result, they are cutting down forests for fuel, encroaching on marginal lands, and overgrazing grasslands with livestock. A lack of laws and regulations in this area may be linked to the deterioration of the local environment.

As in many other parts of the world, environmental degradation is becoming so severe that it undermines economic growth in South Asia. According to the World Bank [17], South Asian countries should take immediate action to reduce their carbon emissions. If this is not done, the impact will become even more severe. Growth in the economy, which can be encouraged through liberalization and industrialization policies, brings gains from a short-term perspective. In the long run, however, it increases the vulnerability of South Asian countries to environmental deterioration and the risks that are associated with it. The article presents some newly released research results on the relationship between economic expansion and environmental degradation in that region. These results are shown in Table 1.

Table 1. Literature review on environmental degradation in South Asian countries. Recently published papers.

Author(s)	Country/Period	Variables	Results
Khan et al. [18]	5 South Asian countries (1972–2017)	CO ₂ emissions, economic growth, non-renewable energy consumption, KOF index of globalization	The results support the inverted U-shaped EKC hypothesis. Research identified the causality between GDP growth and carbon emissions and found bidirectional causality between economic growth and energy use.
Tan et al. [9]	South and Southeast Asian countries (2013–2019)	biodiversity loss, economic growth, agricultural land, corruption	The results strongly support an inverted U-shaped relationship between income and biodiversity loss. Control of corruption and biodiversity loss are negatively associated, while agricultural land has a significant and positive effect on biodiversity loss.
Sadiq et al. [6]	5 South Asian countries (1972–2019)	CO ₂ emissions, economic growth, non-renewable energy consumption, KOF index of globalization	The results support the inverted U-shaped EKC hypothesis. Economic growth Granger causes CO ₂ emanations. Heavy dependence on fossil energy consumption is not environmentally friendly for sustainable development in this region.
Mehmood et al. [8]	4 South Asian countries (1972–2019)	CO ₂ emissions, economic growth, renewable energy consumption, tourism	The results support the inverted U-shaped EKC hypothesis in Pakistan and India. The findings show mixed results regarding the impact of tourism on CO ₂ emissions.
Sharma et al. [19]	4 South Asian countries (1990–2016)	carbon intensity, economic growth, renewable energy consumption, stock market capitalization, technological innovations, trade	Stock market development, per capita income, and trade expansion increased carbon intensity in South Asian countries.
Murshed et al. [20]	South Asian countries (1995–2015)	CO ₂ emissions, ecological footprints, economic growth, renewable energy consumption	The results confirmed the validity of the EKC hypothesis. The use of renewable energy is associated with environmental betterment in all five South Asian countries. The results imply that economic growth is both the short-run cause and long-run solution to the environmental adversities in South Asian countries.
Fong et al. [21]	9 South-east Asian countries (1993–2012)	SO ₂ emissions, NO _x , PM2.5 concentration, economic growth, renewable energy consumption, primary energy intensity, urban population, services sector, foreign direct investment	The results support the inverted U-shaped EKC hypothesis for all pollutants. Spatial spillovers are not found for NO _x emissions but are supported for SO ₂ and PM2.5 emissions. Most countries are still on the upward sloping portion of the curve.
Ullah and Awan [22]	Developing Asian countries (1973–2010/2016)	CO ₂ emissions, SO ₂ emission, PM2.5 concentration, economic growth, income inequality, foreign direct investment, trade openness, population density, urban population	The results support the inverted U-shaped EKC hypothesis. Moreover, the findings reveal that income inequality is positively related to CO ₂ and SO ₂ emissions and PM2.5 concentrations.

2.2. Energy Consumption and Environmental Degradation

Economic prosperity and growth have always constituted part of the policy agenda of every country. They are of utmost importance for South Asian countries, where 40 percent of the world's poor live. Excessive population leads to excessive human activity and excessive consumption of energy, which results in CO₂ emissions. Nowadays, South Asian countries can achieve improved economic growth, but at the cost of environmental degradation caused by increased consumption of natural resources [23]. Consequently, they are confronted with the dual problem of generating higher economic growth while at the same time containing the progression of environmental damage. This is particularly apparent in

South Asian countries, which are desperate to achieve higher economic growth to alleviate poverty and improve the standard of living. By comparison, developed countries face fewer challenges. Energy consumption is one of the most significant variables for rapid economic expansion, industrialization, and urbanization. This consumption in South Asian countries comes from non-renewable energy sources, in particular oil, coal, and natural gas, which in turn drive carbon dioxide emissions.

The connection between rising energy use and worsening environmental conditions is significant from the point of view of economic policy. Much research has been carried out to investigate this nexus, taking into account a variety of energy sources utilized in South Asian nations. For instance, Rahman [24] found that the use of energy had a negative long-term impact on the quality of the environment in a group of 11 Asian countries over the period 1960–2014. Similar findings were published by Dong et al. [25]. They found that using natural gas had a considerable negative influence on CO₂ emissions for a panel of 14 Asia-Pacific nations between 1970–2016. In their study, Munir and Riaz [26] reviewed the data of three South Asian countries (Pakistan, India, and Bangladesh) from 1985 to 2017, and concluded that an increase in the use of gas, coal, and electricity led to a rise in CO₂ emissions. Mujtaba et al. [27] demonstrate that a positive shock in oil prices is associated with an increase in energy consumption, which in turn has a positive and significant influence on CO₂ emissions in India. Additionally, the research findings regarding the amount of foreign direct investment brought into this country lend credence to the pollution haven hypothesis.

It is interesting to note that the consumption of renewable energy has a positive impact on environmental quality in this region. This is something that should be taken into consideration. A significant portion of the existing body of knowledge focuses on this problem. Recent research by Anwar et al. [28] shows that the use of renewable energy sources resulted in lower carbon dioxide emissions in 15 Asian economies from 1990 to 2014. Additionally, Murshed et al. [20] found that increasing the levels of renewable energy consumption and renewable electricity outputs reduced the ecological and carbon footprints of five South Asian economies (Bangladesh, India, Pakistan, Sri Lanka, and Nepal) during the period 1995–2015. Similar results for different regions and countries were published by Shahbaz et al. [29], Ma et al. [30], Ulucak and Yucel [31], and Erdogan et al. [32].

The continued expansion of economic activity in South Asian countries along with a growing population will boost energy consumption in the following decades. It is anticipated that by 2040 the demand for energy in developing countries, including South Asian countries, will be 33 percent higher than it is today. However, the current economic growth patterns in this region, particularly in India, are environmentally unsustainable due to the country's reliance on fossil fuel-based energy consumption and imported crude oil, which significantly degrade the environment. This is especially true in India [29].

2.3. Trade Openness and Environment Degradation

The advent of globalization has made it possible for numerous nations to engage in cross-border international transactions. Since the opening of the economy in the early 1990s, a growing body of literature has investigated the impact of trade openness on the environment. This nexus is essential for policy-makers because it will assist them in achieving their goals of simultaneously accelerating economic growth and improving environmental quality. Though the nexus is significant from the point of view of policy-makers, the environmental implications of trade openness have not received much attention in South Asian nations.

The impact of trade openness on pollution is described by means of the scale effect, composition effect, and technology effect. The scale effect is connected with adverse environmental consequences. It is believed that trade openness causes pollutant emissions due to increased economic activity. Trade increases production volume and energy use, which in turn causes an increase in CO₂ emissions and a decline in environmental quality.

The composition effect is based on the principles of factor endowment or the Heckscher Ohlin theory. Therefore, the economy should focus on the industries with a competitive advantage. Countries with abundant labor supply should specialize in and export labor-intensive products. Similarly, countries where capital is abundant should specialize in and export capital-intensive products. The South Asian nations, where there is a plentiful supply of labor, should specialize in and export goods that need much labor. Theoretically, labor-intensive industries should not cause an increase in pollution. However, several study findings indicate that trade openness has a detrimental impact on the environment of lower-income countries, where “dusty industries” are exported by industrialized nations, according to the factor endowment theory and pollution haven hypothesis [33]. The policy-makers feel that the developing and less developed nations pursue rapid economic growth to raise their living standards and combat poverty. Consequently, they are relaxing environmental rules and regulations to attract more foreign direct investors, who take advantage of lax legislation and harm the host country’s environment [34].

The technological effects of trade openness bring modern eco-friendly technology that will reduce pollution. The question arises among policy-makers, researchers, and practitioners under what circumstances trade openness benefits the environment. Trade is environmentally beneficial as long as the technological effects outweigh the scale and composition effects. The empirical findings on the trade-environment nexus in developing nations are unresolved in this regard and need to be empirically tested.

There are two camps of opinion on the impact of international trade on CO₂ emissions. On the one hand, it is contended that trade openness enables each nation to gain access to the world market, and in this way increase its market share. Access to global markets encourages less developed and emerging nations to import more environmentally friendly, energy-efficient, and modern technologies to replace the outdated ones. As a result, pollution levels decrease [35,36]. The studies that support a positive association between trade openness and environmental quality are Ahmed et al. [37], Antweiler et al. [38], Copeland and Taylor [39], Cherniwchan [40], Dogan and Turkekul [41], Frankel and Rose [42], Kanjilal and Ghosh [43], and Shahzad et al. [44].

On the other hand, it is claimed that trade openness adversely affects the quality of the environment as it leads to large-scale export production and the establishment of “manufacturing hubs”, and what follows higher energy use and higher CO₂ emissions. Foreign trade increases foreign direct investments in the industrial and logistics sectors, which are energy-based activities that lead to an increase in emissions, according to Hakimi and Hamdi [45], and Lopez [46]. Schmalensee et al. [47], and Copeland and Taylor [48] argue that growing global trade is to blame for the depletion of natural resources, which in turn results in higher CO₂ emissions and worse environmental conditions. Other researchers who share the view that trade openness increases pollution include: Al-Mulali and Sheau-Ting [49], Jun et al. [34], Jalil and Feridun [50], Kellenberg [51], Managi and Kumar [52], Shahbaz et al. [53]. Because of this, we decided to verify the hypothesis that trade openness significantly impacts carbon dioxide emissions in South Asian countries.

It is interesting to note that the literature suggests conflicting and mixed impacts between trade openness and CO₂ emissions, demonstrating the inconsistency of the findings. One of the reasons why these results are inconsistent is connected with different levels of economic development in the countries under study. Le et al. [54], for instance, assert that trade openness increases pollution in middle- and low-income nations while reducing it in high-income countries. Similarly, Baek et al. [55] found that trade openness negatively affected the environment’s quality in less developed nations due to failure to enforce laws and regulations. On the other hand, strict environmental regulations in industrialized nations drove multinational corporation investment overseas.

Another reason for the inconsistent results is the quality of the economic policy. This is exemplified in the studies undertaken by Grossman and Krueger [56], who argue that the environmental impact of international trade depends on economic policies; Copeland [57], who highlights that trade openness improves environmental quality in the presence of

good governance; and Chang [58], who found that trade openness reduced CO₂ emissions in countries with low levels of corruption while increasing CO₂ emissions in countries where corruption was high.

Contrary to the findings above, some authors argue that there is no association or insignificant effect between trade openness and environmental pollution: Farhani et al. [59], Jalil and Mahmud [60], Jayanthakumaran et al. [61], and Sharma [62]. Our study will fill the literature gaps.

3. Data and Methods

The paper examines annual data for four South Asian countries: India, Bangladesh, Sri Lanka, and Pakistan. The period for the analysis (1971–2014), was selected based on data availability. The annual time series data came from the World Bank collection of development indicators, and include the following variables: C—carbon dioxide (CO₂) emissions per capita (in metric tons); Y—GDP per capita (in constant 2010 US\$); E—energy consumption per capita (kg of oil equivalent), and T—trade openness (% of GDP). Carbon dioxide emissions are defined as emissions that result from cement manufacturing and fossil fuel combustion. They also include CO₂ emissions produced during the consumption of gas fuels and gas flaring, and liquid and solid fuels. Energy consumption refers to primary energy use; i.e., before it is transformed to other end-use fuels. It is equal to domestic production plus imports and stock changes, minus exports and fuels used in international transport (World Bank Development Indicators). Trade openness is defined as the sum of imports and exports of services and goods measured as a share of GDP.

Table 2 shows a data description. According to the skewness and kurtosis measures, we found that the series of some countries showed evidence of asymmetry, fat tails, and high peaks for all variables. These results indicated that the non-linear ARDL approach is suitable for our analysis. Additionally, we performed the test for parameter instability by Andrews [63] and the Brock, Dechert, and Scheinkman (BDS) test [64] to check the data. The test for parameter instability confirmed the instability for all variables in all countries (Table A1). The BDS test confirmed the failure of the assumption of iid residuals (linear model) for some variables in some countries (Table A2). These results also show that applying the non-linear ARDL approach is appropriate for this study.

Table 2. Descriptive statistics of the variables.

	lnCO ₂	lnE	lnY	lnY ²	lnT	lnCO ₂	lnE	lnY	lnY ²	lnT
	Bangladesh					India				
Mean	−0.828	2.121	2.679	7.194	1.927	−0.150	2.571	2.827	8.030	9.103
Median	−0.867	2.097	2.637	6.956	1.840	−0.156	2.561	2.780	7.730	9.115
Maximum	−0.384	2.360	2.978	8.870	2.625	0.217	2.804	3.215	10.336	9.203
Minimum	−1.278	1.938	2.508	6.292	1.522	−0.441	2.427	2.582	6.664	8.895
Std. Dev.	0.242	0.119	0.133	0.727	0.367	0.190	0.111	0.196	1.126	0.084
Skewness	0.3826	0.1665	0.0315 *	0.0215 *	0.0426 **	0.5562 *	0.1600	0.1731 **	0.1175*	0.0196 *
Kurtosis	0.0683	0.1445	0.4937 *	0.6683 *	0.0906 **	0.0358 *	0.1663	0.0180 **	0.0479*	0.7892 *
Jarque-Bera	2.211	2.879	4.848 *	5.364 *	5.199 *	2.110	2.866	3.615	3.827	5.171 *
Probability	0.331	0.237	0.089	0.068	0.074	0.348	0.239	0.164	0.148	0.075
	Sri Lanka					Pakistan				
Mean	−0.433	2.562	3.147	9.944	2.793	−0.250	2.592	2.858	8.183	2.409
Median	−0.518	2.509	3.116	9.708	2.76	−0.216	2.619	2.894	8.376	2.396
Maximum	−0.072	2.741	3.545	12.565	3.213	−0.060	2.699	3.023	9.138	2.567
Minimum	−0.699	2.458	2.839	8.058	2.390	−0.511	2.455	2.654	7.041	2.269
Std. Dev.	0.212	0.086	0.206	1.313	0.261	0.136	0.078	0.114	0.648	0.077
Skewness	0.3742 ***	0.1176 ***	0.3589 *	0.2415 *	0.8526 ***	0.1211 *	0.1997 ***	0.2594 *	0.3200 *	0.7817
Kurtosis	0.0000 ***	0.0004 ***	0.0374 *	0.0728 *	0.0000 ***	0.0258 *	0.0002 ***	0.0129 *	0.0093 *	0.2074
Jarque-Bera	4.987*	5.033*	2.502	2.701	3.360	3.998	4.467	3.203	3.055	1.155
Probability	0.083	0.081	0.286	0.259	0.186	0.135	0.107	0.202	0.217	0.561

Sources: The authors' estimation. Note: *, ** and *** show the significance at the 10%, 5% and 1% level, respectively.

Our model is based on the EKC hypothesis, which postulates an association between economic growth and environmental degradation. The pattern of economic growth can affect environmental quality in many ways. According to Grossman and Krueger [65], this influence can occur through three channels: scale effect, composition effect, and technique effect. Following the literature (e.g., Soytaş et al. [66], Shahbaz et al. [67], Kyophilavong et al. [68], Kisswani et al. [69], Jóźwik et al. [70], and Soylu et al. [71]), we assume that the EKC has an inverted U-shape. This means that at the initial stage of development, countries focus more on economic growth, which results in increasing environmental pollution and decreasing environmental quality. Once their threshold level of income (i.e., beyond some level of per capita income) has been achieved, they become more concerned about the environment by implementing more restrictive environmental laws and regulations and encouraging investment in eco-friendly projects. As a result, the pollution level is reduced and environmental quality increases.

Our aim is to identify the long-run relationship and causality between environmental degradation, economic growth, energy consumption, and trade openness in South Asian countries. This association can be expressed as follows:

$$CO_2 = f(E, Y, Y^2, T) \quad (1)$$

All data in the model have been transformed into natural logarithms. Thus, the ARDL model (Equation (2)) and NARDL model (Equation (3)) are rewritten as:

$$\ln CO_2_t = \alpha + \beta_1 \ln E_t + \beta_2 \ln Y_t + \beta_3 (\ln Y_t)^2 + \beta_4 \ln T_t + \varepsilon_t \quad (2)$$

$$\ln CO_2_t = \alpha + \beta_1 \ln E_t + \beta_2 \ln Y_t + \beta_3 (\ln Y_t)^2 + \beta_4^+ \ln T_t^+ + \beta_4^- \ln T_t^- + \varepsilon_t, \quad (3)$$

where CO_2 is carbon dioxide emissions in metric tons per capita in year t , E_t is energy consumption in kilogram of oil equivalent per capita, Y_t is real GDP per capita (in constant prices 2010 US\$), Y_t^2 is real GDP per capita squared, T_t defines trade openness (% of GDP), T_t^+ and T_t^- represent positive and negative shocks of foreign trade (trade openness), and ε_t is the error term. As was pointed out earlier all the data were collected from the World Bank (World Development Indicators).

The sign of the coefficient β_1 , which is associated with energy consumption, is usually positive, indicating that an increase in energy consumption, which leads to higher economic growth, triggers CO_2 emissions. But recent research has suggested that the impact of energy consumption on environmental quality is heavily conditional and dependent on energy sources; for example, Fatima et al. [72], Saidi and Omri [73], Ma et al. [30], and Shahbaz [29]. In our research, it is essential to note that the majority of South Asian countries have traditionally been overwhelmingly dependent on non-renewable fossil fuels to meet their increasing energy demand [20,74].

The signs of coefficients β_2 , and β_3 associated with GDP per capita can have positive and negative values. According to the inverted U-shaped EKC hypothesis, the relationship requires that β_2 should be positive and β_3 should be negative [75,76]. If coefficient β_3 is statistically insignificant, there is a monotonic increase in the relationship between CO_2 emissions per capita and real GDP per capita.

In liberalized South Asian countries, the expected sign of coefficient β_4 associated with GDP per capita is positive. According to Copeland and Taylor [39], the environmental effects of trade liberalization can be classified into five categories: scale effects, structural effects, technology effects, direct effects, and regulation effects. Three of them were explained earlier. The expected sign of the coefficient for trade openness is negative if trade openness promotes energy-efficient technology through the import of new technologies, encouraging cleaner domestic products, and imposing stricter environmental regulations [77]. On the other hand, the coefficient is positive if trade openness increases pollution-intensive export and promotes a pollution haven for foreign direct investment [56,67,78].

The ARDL framework of Equation (2) can be written as:

$$\begin{aligned}\Delta \ln \text{CO}_{2t} = & \alpha + \beta_0 \ln \text{CO}_{2t-1} + \beta_1 \ln E_{t-1} + \beta_2 \ln Y_{t-1} + \beta_3 (\ln Y_{t-1})^2 + \beta_4 \ln T_{t-1} \\ & + \sum_{i=1}^p \zeta_0 \Delta \ln \text{CO}_{2t-i} + \sum_{i=0}^r \zeta_1 \Delta \ln E_{t-i} + \sum_{i=0}^{r1} \zeta_2 \Delta \ln Y_{t-i} \\ & + \sum_{i=0}^{r1} \zeta_3 \Delta (\ln Y_{t-i})^2 + \sum_{i=0}^{r1} \zeta_4 \Delta \ln T_{t-i} + \varepsilon_t\end{aligned}\quad (4)$$

where Δ denotes the operator, r denotes the lag lengths, and ε_t is the error term. The null hypothesis is that there is no relationship (cointegration) between CO_2 emissions and the determinant variables, and the alternative hypothesis states that a long-run relationship (cointegration) between the variables exists.

Additionally, we investigate an asymmetric impact of trade openness on CO_2 emissions. To do this, we apply the NARDL approach, which has been widely used in empirical studies since the mid-1990s, when a substantial body of work considered the joint issues of non-linearity and non-stationarity. Among the recently published studies, we can mention Rahman and Ahmad [79], Qamruzzaman et al. [80], Sheikh et al. [81], and Mujtaba et al. [82]. The main idea of an asymmetric impact is that a positive shock may have a larger absolute effect in the short run while a negative shock has a larger absolute effect in the long run (or vice-versa). The NARDL has several advantages compared to the ARDL model [83]. First, the ARDL approach does not consider the asymmetric relationship between the variables. The positive and negative variations of independent variables have the same effect on the dependent variable. Second, the NARDL approach enables us to test for hidden cointegration, which helps differentiate between linear cointegration, non-linear cointegration, and lack of cointegration. The concept of hidden cointegration (which means that no cointegration is detected when using conventional techniques, but cointegration is found between positive and negative components of the series) was developed by Granger and Yoon [84].

The NARDL framework of Equation (3) can be written as:

$$\begin{aligned}\Delta \ln \text{CO}_{2t} = & \alpha + \delta_0 \ln \text{CO}_{2t-1} + \delta_1 \ln E_{t-1} + \delta_2 \ln Y_{t-1} + \delta_3 (\ln Y_{t-1})^2 + \delta_4^+ \ln T_{t-1}^+ \\ & + \delta_4^- \ln T_{t-1}^- \\ & + \sum_{i=1}^p \zeta_0 \Delta \ln \text{CO}_{2t-i} + \sum_{i=0}^r \zeta_1 \Delta \ln E_{t-i} + \sum_{i=0}^r \zeta_2 \Delta \ln Y_{t-i} \\ & + \sum_{i=0}^r \zeta_3 \Delta (\ln Y_{t-i})^2 + \sum_{i=0}^r \left(\zeta_4^+ \Delta \ln T_{t-i}^+ + \zeta_4^- \Delta \ln T_{t-i}^- \right) + \varepsilon_t\end{aligned}\quad (5)$$

where T_t^+ and T_t^- represent positive and negative shocks of foreign trade (trade openness). The long-run and short-run changes are represented by coefficients δ_i and ζ_i , respectively.

The short-run NARDL model estimations with an error correction mechanism can be estimated with the following equation:

$$\begin{aligned}\Delta \ln \text{CO}_{2t} = & \alpha + \sum_{i=1}^p \varphi_0 \Delta \ln \text{CO}_{2t-i} + \sum_{i=0}^p \varphi_1 \Delta \ln E_{t-i} + \sum_{i=0}^p \varphi_2 \Delta \ln Y_{t-i} \\ & + \sum_{i=0}^p \varphi_3 \Delta (\ln Y_{t-i})^2 + \sum_{i=0}^p \left(\varphi_4^+ \ln T_{t-i}^+ + \varphi_4^- \ln T_{t-i}^- \right) + \psi \text{ECM}_{t-1}\end{aligned}\quad (6)$$

The long-run symmetry and asymmetry are tested with the standard Wald test. The asymmetric cumulative dynamic multipliers effect on $\ln \text{CO}_2$ of a unit change in $\ln T_t^+$ and $\ln T_t^-$ can be obtained as follows:

$$\begin{aligned} m_h^+ &= \sum_{i=0}^h \frac{\Delta \ln \text{CO}_{2t+i}}{\Delta \ln T_t^+} \\ m_h^- &= \sum_{i=0}^h \frac{\Delta \ln \text{CO}_{2t+i}}{\Delta \ln T_t^-} \end{aligned} \quad (7)$$

Finally, we applied the asymmetry causality test developed by Hatemi [85]. The causality testing is asymmetric in the sense that positive and negative shocks may have different causal impacts.

4. Results and Discussion

In the first step, we use the Augmented Dickey-Fuller and Phillips-Perron unit root tests to check if all variables are stationary. The null hypothesis of the ADF and Perron tests is that the variable contains a unit root, and the alternative is that the variable is generated by a stationary process. The results of the tests with intercept and trend can be found in Table A3. The null hypothesis can be rejected at the 1% level of significance for all variables at the first difference. This implies that all variables used in this study are integrated on the order of one $I(1)$.

After confirming the ordering of the integration, we apply the ARDL and NARDL approaches to examine long-run relationships (cointegration) and estimate the coefficients. To implement these approaches, the selection of appropriate lag length is necessary. We chose one lag based on the results of Akaike's information criterion and Schwarz's Bayesian information criterion. Tables 3 and 4 provide the results of ARDL and NARDL tests for cointegration. In the NARDL test, the null hypothesis of no cointegration between variables was rejected at the 10% level of significance in Bangladesh, India and Pakistan, and at 5% in Sri Lanka. The estimated F-statistics were larger than the critical upper bounds. The results of the NARDL test were more significant (Table 4). The null hypothesis was rejected at the 1% level of significance in India and Pakistan, and at 5% in Bangladesh. We also rejected the null hypothesis for Sri Lanka, accepting that the F-statistic was slightly smaller than the upper bound at the 10% level of significance. In summary, these results show that all equations are co-integrated.

Table 3. Results of the ARDL test for cointegration. Model: $\ln \text{Co}2 = f(\ln E, \ln Y, \ln Y^2, \ln T^+, \ln T^-)$.

Country	F-Statistic	Result
Bangladesh	25.571 *	Cointegration
India	7.840 *	Cointegration
Sri Lanka	3.071 **	Cointegration
Pakistan	8.038 *	Cointegration
Critical Value for F-Statistic	Lower Bound $I(0)$	Upper bound $I(1)$
1%	3.29	4.37
5%	2.56	3.49
10%	2.2	3.09

Sources: The authors' estimation. Note: * and ** show the significance at 10%, 5% and level respectively.

The differences between coefficients estimated by the ARDL and NARDL approach are highlighted in Table 5. The NARDL estimation captures richer insights into the asymmetric effects of trade openness on CO_2 emissions. As specified in Equation (3), trade openness is split into positive and negative shocks in the NARDL model. Table 5 compares the long-run and short-run coefficients.

Table 4. Results of the NARDL test for cointegration. Model: $\text{LnCo2} = f(\text{LnE}, \text{LnY}, \text{LnY}^2, \text{LnT}^+, \text{LnT}^-)$.

Country	F-Statistic	Result
Bangladesh	3.473 **	Cointegration
India	18247.93 ***	Cointegration
Sri Lanka	2.901 *	Cointegration
Pakistan	4.291 ***	Cointegration
Critical Value for F-Statistic	Lower Bound I(0)	Upper bound I(1)
1%	3.06	4.15
5%	2.39	3.38
10%	2.08	3.00

Sources: The authors' estimation. Note: *, ** and *** show the significance at 10%, 5% and 1% level respectively.

Table 5. Results of ARDL and NARDL tests.

Variables	Bangladesh	India	Sri Lanka	Pakistan	Bangladesh	India ¹	Sri Lanka	Pakistan
ARDL Analysis Results								
Long-run coefficients					Short-run coefficients ¹			
lnE	0.781	0.555	1.074	0.889 *	1.543 *	0.000	2.040 *	1.248 *
lnY	3.022	7.594 ***	−10.268 **	5.246 *	2.522	−0.012	21.455 *	15.451 *
lnY ²	−0.315	−1.097 ***	1.427 **	−0.813 *	−0.159	0.002	−3.472 *	−2.614 *
lnT	−0.122 ***	−1.755	1.554 *	0.076	−0.041	−0.999 *	0.524 **	0.016
C	−8.107	0.798	10.605	−11.081 *				
ECT _{t−1}					−0.938 *	0.001 *	−0.611 *	−0.707 *
NARDL Analysis Results								
Long-run coefficients					Short-run coefficients			
ΔlnE	5.550	0.978	0.827	0.945 ***	37.464 ***	0.007	1.976 ***	1.153 ***
ΔlnY	−0.108	0.021	−12.173 **	9.985 ***	−7.349 ***	−0.003	19.006 ***	−2.176
ΔlnY ²	−3.625	−1.180 *	1.663 **	−1.787 ***	0.940 ***	0.004	−3.111 ***	0.429
ΔlnT_NEG	−0.075	−2.209 ***	1.594 **	0.157 ***	−0.106 **	−1.002 ***	−0.171	0.115 *
ΔlnT_POS	0.255	0.272	1.877 **	0.461	0.179 ***	−0.996 ***	1.087 ***	−0.056
C	−7.366	−1.177	18.562 *	−16.708 ***				
ECT _{t−1}					−0.289 ***	0.011 ***	−0.684 ***	−0.555 ***

Sources: The authors' estimation. **Notes:** ¹ The lag length for CO₂ in India is 2; thus, additional coefficients were estimated: 0.825 * (ΔLNCO_{2,t−1}); −0.001 (ΔLNE_{t−1}); −0.020 ** (ΔLNY_{t−1}); 0.004 ** (ΔLNY_{t−1}); 0.824 * (ΔLNT_{t−1}). *, ** and *** show the significance at the 10%, 5% and 1% level, respectively.

As outlined above, the signs of the coefficients associated with GDP per capita can have positive and negative values. Based on the inverted U-shaped EKC hypothesis, the relationship requires that β_3 should be negative (and β_2 should be positive). We observe similar coefficients in the ARDL and NARDL models. Similarly, Dong et al. [25], Murshed et al. [20], Khan et al. [18], and Sadiq et al. [6] proved the inverted U-shaped EKC hypothesis in that region. Dong et al. [25] pointed out that the turning points lie at \$1181.60 in Pakistan, \$1861.49 in India, and \$1937.23 in Bangladesh, while the turning years were estimated in 2041, 2039, and 2048, respectively. Other studies indicate that using renewable energy is associated with environmental betterment [20], and sustainable development policies can revisit the conflict between globalization and environmental degradation [6,18].

In the NARDL model, the long-run coefficient for squared GDP per capita is negative and significant in India (−1.180 *) and Pakistan (−1.787 ***), while it is positive in Sri Lanka (1.663 **). The coefficients for India and Pakistan indicate that we should expect increased environmental quality. Notably, the Indian government has taken many initiatives to reduce environmental degradation in recent years. For example, the International Solar Alliance's launch summit was co-chaired by Prime Minister Narendra Modi and French President Emmanuel Macron in March 2018, demonstrating India's leadership in supporting renewable energy (ISA). In January 2019, the Ministry for Environment introduced the National Clean Air Program (NCAP), which gives the states and union government a framework to tackle air pollution. Since 2018, India's 2019 climate change index (CCPI) performance has improved from 14th to 11th place [86]. Pakistan has recently given se-

rious thought to addressing the world's escalating environmental concerns, according to the United National Development Program 2020. Several Acts have been promulgated along with some policies and public sector initiatives currently in effect. For example, clean and green initiatives have been implemented; environmental protection agencies at the federal and provincial levels have been strengthened; environmental laboratories and courts, national environment quality standards, the National Energy Efficiency and Conservation Authority (NEECA), and national environmental quality standards have all been developed [87].

Another potential environmental problem is that the coefficient associated with GDP per capita is relatively high in Pakistan. Let us recall at this point that the coefficients of GDP per capita indicate the scale effect, which is associated with adverse environmental consequences. It is highly probable that high trade openness causes pollutant emissions due to increased economic activity. Our study corroborates the findings by Ullah et al. [88] and Khan et al. [89], who found that trade liberalization (trade openness) led to increased CO₂ emissions in Pakistan. This positive relationship can be explained by scale effects where large-scale manufacturing operations, particularly in fossil-fueled and export-oriented industries, increase emissions of pollutants. This is because in the early stages of the development process, more emphasis is placed on economic growth than on pollution control. At this stage, less developed countries are often "hungry" for rapid economic growth to fight against poverty. The negative sign of β_2 in Sri Lanka should definitely be assessed in a positive way.

The results of the long-run coefficients associated with energy consumption, both in the ARDL and NARDL model, surprised us. Usually, energy consumption significantly impacts the dioxide carbon emissions in such a way that there is a positive long-run relationship between these two (cf. Wang et al. [90], Gierałowska et al. [91] and Verbič et al. [92]). Energy consumption should likely be associated with other factors. This relationship is visible in developed countries. For example, Wang et al. [90] indicate that energy intensity and foreign direct investment and urbanization strongly impact carbon dioxide emissions. In our research, these long-run coefficients are significant only in Pakistan (ARDL 0.889 * and NARDL 0.945 ***). By contrast, these coefficients are highly significant in the short run in Bangladesh (37.464 ***), Sri Lanka (1.976 ***), and Pakistan (1.153 ***) in the NARDL model.

The most interesting finding was that the long-run coefficients associated with trade openness shocks, both negative and positive, significantly impacted CO₂ emissions only in Sri Lanka (at the significance level of 5%). These research results did not support the hypothesis that trade openness significantly impacts carbon dioxide emissions in South Asian countries. The estimated coefficients of trade openness with positive and negative shocks are 1.887 and 1.594, respectively. Therefore, increasing trade openness by 1% increases carbon dioxide emissions by 1.887%, while reducing trade openness decreases carbon dioxide emissions by 1.594%. These impacts are based on the scale effect. The primary contributors to Sri Lanka's economy are tourism, tea export, textile and garment manufacturing, rice and other agricultural goods, and food products. Gasimli et al. state that domestic investors do not use environmentally friendly technology [93]. Additionally, imported technology in the form of machinery does not have a positive impact on the environment. In the cases of India and Pakistan, trade openness coefficients are significant at 1% only for negative shocks. For example, in India, an increase in trade openness has no significant impact on carbon dioxide emissions, while a reduction by 1% increases carbon dioxide emissions by 2.209%. Otherwise, a recent study by Shahbaz et al. [94] reports that the discussion on the energy-led growth of India necessitates the cross-border movement of resources, which influences the carbon dioxide emissions pattern. As the Indian import portfolio was majorly dependent on crude oil, the import substitution policies have reduced the import of crude oil and other petroleum products and, consequently, the level of carbon dioxide emissions.

The results for short-run trade openness coefficients, for positive and negative shocks, are significant in Bangladesh and India. Moreover, positive and negative shocks perform

considerably differently in Bangladesh. For example, a positive shock (0.179 ***) impact is greater than a negative shock (-0.106^{**}), which demonstrates that positive shocks have more profound effects than negative shocks. This proves the significant impact of trade openness on the environment in the short run. But in 2021, Sharma et al. [19] published a paper describing the importance of importing innovative solutions to reduce environmental degradation in the long run. Domestic enterprises will try to import innovative technological solutions to improve their energy efficiency and reduce their carbon footprint.

Finally, we examine the stability of the model. Table 6 presents the diagnostic tests for serial correlation, heteroscedasticity, normality, and Ramsey. The diagnostic tests of the ARDL model indicate problems with serial correlation in all countries, heteroscedasticity in Sri Lanka, and non-linearity in Bangladesh and India. However, we found no serial correlation, heteroscedasticity problem, or normality problems in the NARDL. This diagnostic test confirmed that the NARDL was more appropriate than the ARDL model.

Table 6. Diagnostic checks of the ARDL and NARDL tests.

Test	Bangladesh	India	Sri Lanka	Pakistan
ARDL Analysis Results				
Serial Correlation	0.000	0.000	0.060	0.006
Heteroscedasticity	0.174	0.172	0.090	0.629
Normality	0.784	0.391	0.819	0.553
Ramsey	0.092	0.013	0.714	0.431
NARDL Analysis Results				
Serial Correlation	0.341	0.112	0.029	0.364
Heteroscedasticity	0.717	0.731	0.107	0.152
Normality	0.664	0.598	0.853	0.612
Ramsey	0.318	0.036	0.601	0.841

Sources: The authors' estimation. Note: They are *p* values.

5. Conclusions and Recommendations

In recent years, environmental pollution has become a global threat. In this study, we attempted to establish the short-run and long-run relationships among environmental degradation, economic growth, energy consumption, and trade openness in South Asian countries. Additionally, we verified the hypothesis that trade openness significantly impacts carbon dioxide emissions in South Asian countries. To do so, we used annual data for four South Asian countries (India, Bangladesh, Sri Lanka, and Pakistan) covering the period between 1971 and 2014. Our selection of countries for the study was based on the availability and uniformity of data in that period. We used the linear ARDL and non-linear ARDL (NARDL) model, which allowed us to analyze the impact of positive and negative shocks in trade openness on CO₂ emissions. Both methods show the long-run equilibrium relationship between environmental degradation, economic growth, energy consumption, and trade openness. The empirical outcome shows that the environmental Kuznets curve holds for India and Pakistan out of the four analyzed countries.

In the NARDL model, the long-run coefficients for squared GDP per capita are statistically significant and negative for India and Pakistan, while for Sri Lanka they are statistically significant and positive. Bangladesh's squared GDP per capita is negative but not statistically significant. According to the environmental Kuznets curve, the coefficients for India and Pakistan indicate that environmental quality is expected to improve as income increases in the long run. The estimated long-run coefficients associated with energy consumption in the ARDL and NARDL models surprised us. They are statistically significant only in Pakistan. This indicates that energy consumption significantly aggravated environmental degradation only in Pakistan. This may be associated with poor institutional quality due to political instability in Pakistan.

The most interesting finding was that the long-run coefficients associated with trade openness shocks, both negative and positive, significantly impact CO₂ emissions only in

Sri Lanka. These impacts are based on the scale effect. On the other hand, the results for short-run trade openness coefficients, for positive and negative shocks, are significant in Bangladesh and India. In Bangladesh, positive shock increases carbon dioxide emissions, while negative shock decreases them. However, positive and negative shocks in India reduce environmental pollution. These research results did not support the hypothesis that trade openness significantly impacts carbon dioxide emissions in South Asian countries.

This study has some policy implications. But first, we assumed that if the environmental Kuznets curve is confirmed over a long period in India and Pakistan, there is a high probability that this relationship will exist for a long period. Then we can propose some recommendations. South Asian countries' governments require adequate policy directions to use clean energy while producing output and generating income. Like other low- and middle-income countries, they have limited environmental regulatory capacity. Due to poverty, low-income populations rely on timber wood for food and heating in the winter, causing significant pollution. The region's reliance on fossil fuel energy consumption is not environmentally friendly for long-term development. The consensus believes that developing renewable energies, including wind, solar, and hydroelectric power plants, will replace the infrastructure powered by fossil fuels.

With increased income in this region, governments should prioritize green growth, which is critical for sustainable development. Such actions have been taken in the past. For example, the Pradhan Mantri Ujjwala Yojana (PMUY) is a flagship scheme of India launched on 1 May 2016, by Hon'ble Prime Minister Shri Narendra Modi. The program aims to make clean cooking fuels such as LPG available to rural and deprived households that would otherwise rely on traditional cooking fuels such as firewood, coal, or cow-dung cakes. From a practical point of view, the Indian government should focus on maintaining an affordable price for LPG cylinders, along with taking more steps toward poverty reductions and keeping inflation at a desirable level, especially nowadays when its rate is high. Otherwise, poor people will revert to traditional food preparation methods, which can cause severe health and environmental problems. Consequently, Ujjwala Yojana policy paralysis may occur, leading to increased carbon dioxide emissions.

To combat environmental pollution, the governments in South Asian countries should promote and subsidize green energy by increasing their R&D spending, among others. The fifth-largest economy in the world, India, should take the lead in reducing pollution in the region. Usually, as income levels rise, so does the demand for a cleaner environment, putting pressure on the government to enact stricter environmental regulations. Governments should focus on developing advanced technology, implementing strict environmental policies, and introducing carbon pricing for polluting industries to contribute to sustainable development. Policy-makers should implement some measures to raise environmental standards without lowering income and output levels. Additionally, the financial sector should support companies and households that use environmentally friendly projects to reduce pollution. These findings should be helpful both to policy-makers when developing environmental and trade policies in the South Asian region, and practitioners. There is also a need for more and more awareness to be created among the students at primary, secondary, and tertiary education levels for effective energy utilization and moving toward green energy. All these efforts may provide desirable outcomes. We assume that the success or failure of any policy depends on people's acceptance or rejection of a policy. Therefore, collective efforts are required to reduce pollution.

Although our study has some limitations, it has the scope for further research. The first limitation refers to the sample size. Based on data availability, we examined annual data only for four South Asian countries from 1971–2014. Second, the analysis uses a limited number of factors determining economic growth and environmental degradation. We recommend that other essential variables, such as institutional quality, financial sector development, and urbanization should be considered to understand the relationship between energy use and CO₂ emissions in South Asian countries. Moreover, this study did not examine the specific effects of renewable and non-renewable energy sources on

emissions in South Asian countries. Finally, our research can act as a baseline study for other South Asian countries, as the issues discussed pertain to most developing countries. Therefore, the policy recommendations discussed in the study can be generalized.

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Appendix A

Table A1. The parameter instability test results.

	Bangladesh	India	Sri Lanka	Pakistan
Sup LR	27.730 ***	39.963 ***	6.387 ***	11.134 ***
Sub Wald	138.650 ***	199.814 ***	31.935 ***	55.67 ***
Exp LR	10.432 ***	16.876 ***	1.836 ***	3.877 ***
Exp Wald	65.891 ***	96.474 ***	13.387 ***	25.204 ***
Mean LR	5.556 ***	17.400 ***	2.656 ***	4.842 ***
Mean Wald	27.781 ***	86.999 ***	13.279 ***	24.211 ***

Sources: The authors' estimation. Note: *** shows the significance at the 1% level.

Table A2. The Brock, Dechert, and Scheinkman (BDS) tests results.

	Dimension	lnCO ₂	lnE	lnY	lnY ²	lnT
Bangladesh	2	1.057	0.509	4.06 ***	3.863 ***	2.592 ***
	3	0.407	−0.436	4.838 ***	4.566 ***	2.336 **
	4	0.379	−0.759	5.552 ***	5.3 ***	2.448 **
	5	0.704	0.036	5.908 ***	5.66 ***	2.536 **
	6	0.593	−0.208	6.192 ***	5.969 ***	2.552 **
India	2	0.021	−0.917	0.218	−0.433	0.122
	3	−0.889	−2.39 **	0.316	−0.345	−1.235
	4	−0.781	−1.679 *	−0.037	−0.78	−0.993
	5	−1.14	−1.333	0.272	−0.39	−0.963
	6	−1.079	−1.044	0.572	−0.089	−0.735
Sri Lanka	2	−2.209 **	1.617	1.968 **	2.319 **	1.196
	3	−2.083 **	0.719	1.112	0.974	1.587
	4	−1.852 *	0.576	−0.154	−0.335	1.84 *
	5	−1.169	0.642	−0.237	−0.669	1.341
	6	−0.564	0.619	−0.606	−1.183	1.335
Pakistan	2	0.351	−1.247	0.366	0.348	−0.202
	3	0.004	−1.497	0.226	0.031	0.072
	4	−0.465	−1.938*	−0.408	−0.695	−0.035
	5	−0.073	−1.605	−0.53	−0.505	0.232
	6	−0.097	−1.118	−0.921	−0.804	−0.495

Sources: The authors' estimation. Note: *, ** and *** show the significance at the 10%, 5% and 1% level, respectively.

Table A3. ADF and PP unit root tests results.

Variable	ADF Test				PP Test			
	At Level		At First Difference		At Level		At First Difference	
	Intercept	With Trend	Intercept	With Trend	Intercept	With Trend	Intercept	With Trend
Bangladesh								
lnCO ₂	−1.726 (0)	−13.956 *** (0)	−33.796 *** (0)	−32.765 *** (0)	−1.957 (3)	−9.249 *** (5)	−30.575 *** (1)	−29.935 *** (3)
lnE	1.679 (1)	−1.001 (0)	−8.252 *** (0)	−8.656 *** (0)	2.126 (6)	−1.001 (0)	−8.255 *** (2)	−9.015 *** (3)
lnY	2.894 (0)	−2.132 (0)	−0.934 (2)	−12.936 *** (0)	3.312 (1)	−2.129 (4)	−8.810 *** (4)	−15.548 *** (1)
lnY ²	3.351 (0)	−1.672 (0)	−0.674 (2)	−12.549 *** (0)	3.810 (1)	−1.652 (3)	−8.100 *** (4)	−14.466 *** (1)
lnT	0.049 (0)	−2.648 (0)	0.262 *** (0)	−6.514 *** (0)	−0.063 (1)	−2.990 (8)	−5.556 *** (1)	−6.566 *** (5)
lnT_NEG	−8.490 *** (9)	−10.474 *** (9)	−8.007 *** (9)	−5.809 *** (9)	−10.376 *** (13)	−6.230 *** (7)	−6.291 *** (1)	−7.510 *** (5)
lnT_POS	0.417 (0)	−1.719 (0)	−5.547 *** (0)	−5.509 *** (0)	0.319 (2)	−1.821 (1)	−5.558 *** (2)	−5.523 *** (2)
India								
lnCO ₂	1.694 (0)	−1.064 (0)	−7.228 *** (0)	−7.863 *** (0)	1.917 (2)	−1.106 (3)	−7.209 *** (3)	−7.735 *** (3)
lnE	3.795 (0)	−0.169 (0)	−4.793 *** (0)	−6.152 *** (0)	3.669 (2)	−0.345 (3)	−5.023 *** (4)	−6.210 *** (3)
lnY	3.305 (0)	−1.830 (0)	−6.388 *** (0)	−8.280 *** (0)	5.396 (5)	−1.940 (4)	−6.386 *** (4)	−14.602 *** (10)
lnY ²	4.040 (0)	−1.327 (0)	−5.741 *** (0)	−8.158 *** (0)	6.890 (6)	−1.363 (6)	−5.802 *** (4)	−14.638 *** (12)
lnT	2.429 (0)	−0.318 (0)	−3.225 ** (1)	−7.844 *** (0)	2.939 (1)	−0.226 (3)	−6.722 *** (4)	−7.717 *** (3)
lnT_NEG	2.662 (0)	−2.076 (3)	−2.745 * (1)	−3.128 (1)	2.391 (3)	−0.754 (4)	−6.080 *** (4)	−6.784 *** (4)
lnT_POS	−1.908 (0)	−1.586 (0)	−7.137 *** (0)	−7.404 *** (0)	−2.409 (8)	−1.460 (2)	−7.267 *** (4)	−8.838 *** (9)
Sri Lanka								
lnCO ₂	−0.070 (0)	−2.243 (0)	−7.258 *** (0)	−7.409 *** (0)	0.099 (3)	−2.178 (2)	−7.258 *** (0)	−7.411 *** (1)
lnE	0.078 (0)	−2.335 (0)	−7.290 *** (0)	−6.521 *** (1)	0.436 (5)	−2.157 (2)	−7.399 *** (2)	−7.840 *** (6)
lnY	3.038 (0)	−0.709 (0)	−5.867 *** (0)	−6.445 *** (0)	3.203 (4)	−0.767 (1)	−5.870 *** (2)	−6.432 *** (2)
lnY ²	3.830 (0)	−0.233 (0)	−5.226 *** (0)	−6.135 *** (0)	4.149 (5)	−0.330 (2)	−5.258 *** (2)	−6.144 *** (2)
lnT	3.830 (0)	−0.233 (0)	−5.226 *** (0)	−6.135 *** (0)	4.149 (5)	−0.330 (2)	−5.258 *** (2)	−6.144 *** (2)
lnT_NEG	−2.304 (0)	−3.464 * (0)	−6.790 *** (0)	−6.872 *** (0)	−2.362 (3)	−3.456 * (2)	−6.826 *** (2)	−6.905 *** (2)
lnT_POS	−0.137 (0)	−2.570 (0)	−6.099 *** (0)	−6.022 *** (0)	−0.115 (3)	−2.719 (1)	−6.119 *** (4)	−6.035 *** (4)
Pakistan								
lnCO ₂	−0.690 (0)	−1.808 (0)	−8.538 *** (0)	−8.947 *** (0)	−0.695 (1)	−2.173 (3)	−8.303 *** (2)	−9.035 *** (1)
lnE	−2.111 (0)	0.349 (0)	−5.085 *** (0)	−5.768 *** (0)	−1.986 (2)	0.243 (1)	−5.110 *** (2)	−5.769 *** (1)
lnY	−1.846 (1)	−1.468 (1)	−5.675 *** (0)	−5.969 *** (0)	−1.117 (3)	−1.303 (3)	−5.758 *** (3)	−5.982 *** (2)
lnY ²	−1.588 (1)	−1.581 (1)	−5.565 *** (0)	−5.749 *** (0)	−0.934 (3)	−1.452 (3)	−5.612 *** (2)	−5.754 *** (1)
lnT	−2.052 (0)	−4.724 *** (0)	−6.958 *** (0)	−6.778 *** (0)	−2.293 (3)	−4.782 *** (2)	−7.475 *** (4)	−7.282 *** (4)
lnT_NEG	−0.251 (0)	−3.165 (0)	−7.298 *** (0)	−7.263 *** (0)	−0.004 (6)	−3.165 (0)	−8.482 *** (7)	−9.317 *** (8)
lnT_POS	−0.52 (0)	−2.6 (0)	−6.132 *** (0)	−6.062 *** (0)	−0.518 (2)	−2.741 (1)	−6.128 *** (2)	−6.055 *** (2)

Note: *, ** and *** show the significance at 10%, 5% and 1% level respectively.

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