

Causality analysis of CO₂ emissions, foreign direct investment, gross domestic product, and energy consumption: Empirical evidence from SAARC countries

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Abstract

Over the period 1980-2016, this study looks into the causal relations among CO₂ emissions, energy consumption (EC), foreign direct investment (FDI), and gross domestic product (GDP) in SAARC countries. To achieve the research objectives, panel unit root tests, panel cointegration autoregressive distributed lag model, and Granger causality tests are used. In the long-run, income has a positive impact on CO₂ emissions, while squared income has a negative impact, confirming the occurrence of the Environmental Kuznets Curve (EKC) theory in SAARC countries. Among all SAARC countries, Bangladesh and Nepal support the pollution haven hypothesis, but India, Pakistan, and Sri Lanka support the pollution halo hypothesis. EC has a large positive impact on CO₂ emissions across the country. In the long-run, the Granger causality test confirms one-way causation from EC to CO₂ emissions and bidirectional causality of FDI and CO₂. As a result, these countries might encourage clean energy technology through FDI without jeopardising GDP and environmental quality. This will allow these countries to reduce CO₂ emissions to achieve a long-term green GDP and combat global warming.

1. Introduction

The world has tackled the challenges of worldwide warming and climate change issues throughout the last few decades. Despite substantial climate change due to greenhouse gas (GHG) emissions, the world community has endeavoured to meet these global environmental issues and preserve the planet's habitability. The Paris agreement under the United Nations Framework Convention on Climate Change (UNFCCC), for example, was a significant step toward addressing this environmental crisis. The major goal of this agreement is to reduce GHG emissions to keep global warming below 2 degrees Celsius (UNFCCC 2015). GHG emissions from the burning of fossil fuels in conjunction with various economic activities are major contributors to global climate change. Floods, droughts, and wildfires are some of the paraphernalia of climate change brought on by GHG emissions (IPCC 2014). It also leads to negative health effects from smog and air pollution, such as asthma and respiratory illnesses (IPCC 2014). Climate change also has a negative impact on crop productivity in many areas, resulting in food insecurity and poverty, particularly in developing countries (IPCC 2014). The IPCC emphasises the importance of anthropogenic carbon dioxide (CO₂) emissions, which account for the majority of global GHG emissions. Over 80% of GHG emissions are caused by CO₂ emissions, which are mostly generated by emerging countries seeking to fast-track their economic growth (EG) and increase domestic production to take advantage of expected economic conditions (IPCC 2019).

In recent years, the relationship between environmental pollutants, GDP, foreign direct investment (FDI), and energy consumption (EC) has gotten a lot of attention when it comes to climate change. Grossman and Krueger (1994) use the Environmental Kuznets Curve (EKC) theory to explain the link between environmental pollution and economic growth (EG). The EKC states that environmental contamination rises during the initial periods of economic development and subsequently cascades during the advanced phases (Al-Mulali and Ozturk 2015). FDI, on the other hand, has long been recognized as an important catalyst of EG in developing countries. It creates a lot of opportunities, such as employment, human capital development, technological enhancement, exchange rate stability, improved capital flow, and the creation of competitive markets in the host countries (Asongu et al. 2018). Nonetheless, in recent years, major and commonly discussed concerns about FDI and its negative effects on environmental value and worth have been raised. With the increase in FDI, various studies on FDI determinants in developing countries have been conducted. The environmental directive has been recognized as one of the most important determinants for FDI mobility among a variety of considerations (Hu et al. 2019). To escape expensive production and environmental costs, polluting firms from industrialized countries may invest in developing countries with limited environmental regulation (Islam and Kakinaka 2020). This investment leads to increased EC and CO₂ levels in host countries, and the investing country eventually becomes a "haven" for polluting companies (Hao et al. 2020). The pollution haven hypothesis formalizes this link. Another concept about environmental pollution and FDI is linked with the pollution halo hypothesis, which states that firms from higher-income countries help to decrease GHG emissions in the host nation due to their green technology (Mert and Caglar 2020). EC is regarded as a major input for nearly all commodities and services in any modern economy. There is no possibility for GDP and development to progress without the utilization of energy (Ssali et al. 2019). However, using a hard energy source such as coal-fired power plants, natural gas-fired power plants, or oil refiner, instead of a soft energy source is regrettable. Fast economic expansion and rising energy demand in lower-income and middle-income countries have sparked concerns about supply issues, resource depletion, and environmental effects in recent years. Existing empirical studies have looked into the link between EC, GDP, and GHGs (Vasylieva et al. 2019; Kim 2019). Following that, growing carbon emissions, as well as their relationship with EC and GDP, will be at the forefront of the global warming debate (Sarwar and Wei 2019). As a result, understanding the dynamic link between GHG emissions, FDI, EC, and GDP is important for gaining control over GHG emissions and ensuring the long-term viability of economic development.

The South Asian Association for Regional Cooperation (SAARC) is a regional diplomatic and geopolitical organization made up of eight countries in South Asia. This is one of the most important economic areas for attracting FDI. The key drivers of FDI attraction and EG in these member nations have been recognized as political and macroeconomic stability, a well-designed investment atmosphere, and a plentiful supply of cheap labor (UNCTD 2019). As a result, an increase in FDI may act as a catalyst for increased EC in the SAARC member countries, contributing to CO₂ emissions. These characteristics make the SAARC countries an intriguing case study for analyzing the causal relationships of EC, GDP, FDI, and CO₂ emissions. Although substantial research on GDP and GHG emissions in that region has been conducted to the best of our knowledge, the ability to integrate EC, income, FDI, and GHG emissions into a unified framework is restricted. In light of this, the purpose of this study is to fill in the gaps by looking into the causal relationships of FDI, EC, and GDP with CO₂ to test the hypothesis mentioned above in terms of a few selected SAARC member states. As a result, the key research question is to what extent are EC, FDI, GDP, and CO₂ interrelated in few SAARC member states (such as Bangladesh, India, Pakistan, Nepal and Sri Lanka) from 1980 to 2016? This information is valuable for decision-makers and other partners, such as governments, non-government organizations and business organizations to develop well-informed decisions to ensure ongoing GDP, lower CO₂ emissions, and higher usage of clean investment. The autoregressive distributed lag (ARDL) model and the vector error-correction model (VECM) based on the Granger causality test are used to evaluate the causal relationship between our proposed variables and answer the research questions.

The subsequent segment includes an ephemeral literature review followed by econometric models and data sources. Next, the technical specifics of several econometric approaches are discussed. Following that, the test and model results are shown. The final section contains a summary of the entire study as well as a conclusion with policy recommendations.

2. Related Literature

For the past few years, the causal link between GHG emissions, EC, GDP, and FDI has been a topic of debate (Achour and Belloumi 2016). Social and environmental scientists have spent a lot of effort trying to figure out what causes the variables to interact in the way they do. However, no agreement has been reached on the causal link between the factors because of model misspecification, omitted variables bias, and the inclusion of other irrelevant factors (Niemand and Mai 2018). The technique utilized in the studies on the connection of CO₂ emissions, GDP, EC, and FDI varies, as do the variables considered and the area covered (single country or multi-country). However, the current study, based on earlier research, divides the extant literature into three categories:

2.1 GDP and GHG emissions

The first group of studies examines the association between GDP and CO₂ emissions. Nonetheless, empirical evidence from the existing literature shows inconsistent results (Magazzino et al. 2021; Ameyaw and Yao 2018; Gong et al. 2019; Munir et al. 2020; Cherni and Jouini 2017; Abbasi et al. 2021; Mikayilov et al. 2018; Kim 2019; Mahmood et al. 2019; Hdom and Fuinhas 2020; Cai et al. 2018). According to an extensive body of empirical work, GDP per capita has a favourable impact on GHG emissions (unidirectional). This association was discovered by Narayan and Narayan (2010) and Zhu et al. (2016a) for 43 low-income and five member states of the Association of Southeast Asian Nations, respectively. Some researchers (Agras and Chapman 1999; Richmond and Kaufmann 2006) discovered bidirectional causal relationships between these two variables.

2.2 FDI and GHG emissions

The association of FDI and GHG emissions is examined in the second area of research. This connection has sparked a discussion among the researchers concerning the positive and negative effects of both variables. Rafindadi et al. (2018a) used panel data from 1990 to 2004 to observe the influence of FDI on GHG emissions in a few member states of the Gulf Cooperation Council (CGC). Using the ARDL method, they discovered that FDI encourages GHG emissions. Nguyen (2018) looked into the relationship between FDI and GHG emissions in Vietnam. They discovered a two-way (bidirectional) connection between FDI and CO₂ emissions using the ARDL-Granger causality test. Ssali et al. (2019) examined the causal association of FDI and GHG emissions in six Sub-Saharan African nations. They employed the pooled mean estimator with the ARDL model (ARDL-PMG). In the long-run, their findings revealed a unidirectional causal relationship between CO₂ and FDI, while no causal associations were discovered in the short-run. Likewise, many studies have determined that FDI drives GDP and has a substantial impact on CO₂ emissions (Behera and Dash 2017a; Riti et al. 2017). However, Mert and Bölük (2016) and Sung et al. (2018) found that FDI improves energy efficiency and reduces CO₂ emissions in host nations.

2.3 EC and CO₂ emissions

The final section emphasizes the link between EC and CO₂ emissions. A large body of empirical research found a strong relationship between EC and CO₂ emissions. Through direct or indirect causal relationships, EC is one of the main catalysts of CO₂ emissions (Leito and Balogh 2020; Nguyen 2018). Boutabba (2014) showed unidirectional causality from EC to India's carbon emissions using the ARDL-VECM causality test. Lu (2017), who employed Granger causality in sixteen Asian nations, found similar findings. On the other hand, Dogan and Aslan (2017) found that EC and CO₂ emissions are bidirectional in a few countries of the European Union. Based on the panel cointegration test, Sterpu et al. (2018) showed that an increase in EC leads to an increase in CO₂ emissions in the atmosphere. They also pointed out that, in contrast to fossil fuels, renewable energy sources minimize CO₂ emissions in the atmosphere. All of the research presented in Tables 1, 2, and 3 used single or multiple nation analyses, different timeframes, and several econometric estimations to explain the association between energy consumption and CO₂ emissions. In terms of the number of studies, the results are inconclusive, citing mixed evidence in terms of direction. As a result, it's critical to remember that while studying the link between variables, the influence or direction of the association can change.

Table 1
GDP and GHG emissions

Authors	Variables	Methodology	Relationship
Ameyaw and Yao (2018)	CO ₂ emissions,GDP & EC	ARDL-VECM	GDP→CO ₂
Munir et al. (2020)	CO ₂ emissions, GDP & FDI	VECM	GDP→CO ₂
Cherni and Jouini (2017)	CO ₂ emissions, GDP, EC & population growth	ARDL-DOLS	GDP→CO ₂
Chen et al. (2016)	CO ₂ emissions, GDP & EC	VECM	GDP→CO ₂
Cai et al. (2018)	CO ₂ emissions, GDP & renewable energy	ARDL-VECM	GDP←CO ₂
Abbasi et al. (2021)	CO ₂ emissions, GDP & EC	ARDL-VECM	GDP↔ CO ₂
Magazzino et al. (2021)	CO ₂ emissions, GDP & EC	ARDL-VECM	EKC not valid
Narayan and Narayan (2010)	CO ₂ emissions & GDP	Cointegration analysis	GDP →CO ₂
Gong et al. 2019	CO ₂ emissions, GDP, FDI & urbanization	ARDL-VECM	GDP ↔ CO ₂
Obradović and Lojanica (2017)	CO ₂ emissions, GDP, EC & FDI	VECM	Long-run GDP←CO ₂
Pao and Tsai (2011)	CO ₂ emissions, GDP, EC & FDI	VECM	GDP →CO ₂
Pao and Chen (2019)	CO ₂ emissions, GDP, EC & FDI	VECM	GDP →CO ₂
Hdm and Fuinhas (2020)	CO ₂ emissions GDP & EC	ARDL-VECM	Short run GDP ≠CO ₂ GDP →CO ₂
Saidi and Ben Mbarek (2016)	CO ₂ emissions, nuclear energy, GDP, labour & capital	Dynamic panel	GDP≠CO ₂
Zhu et al. (2016b)	CO ₂ emissions, GDP & FDI	Panel quantile regression	GDP →CO ₂

Table 2
FDI and GHG Emissions

Authors	Variables	Methodology	Relationship
Behera and Dash (2017a)	CO ₂ emissions, FDI, EC & GDP	Pedroni cointegration	FDI→CO ₂ ↑
Lau et al. (2014)	CO ₂ emissions, FDI, GDP & trade openness	ARDL-PMG	FDI→CO ₂ ↑
Mert and Bölük (2016)	CO ₂ emissions, FDI, EC & GDP & income	ARDL-Granger causality	FDI→CO ₂ ↓
Pao and Tsai (2011)	CO ₂ emissions, FDI, EC & GDP	VECM-Granger causality	FDI↔ CO ₂ ↑
Rafindadi et al. (2018a)	CO ₂ emissions, FDI, GDP, EC & relative income	ARDL-DFE	FDI→CO ₂
Seker et al. (2015)	CO ₂ emissions, FDI, GDP & EC	ARDL-VECM	FDI→CO ₂ ↑
Salahuddin et al. (2018)	CO ₂ emissions, FDI, GDP, & EC	ARDL-VECM	FDI→CO ₂ ↑
Sarkodie and Strezov (2019)	CO ₂ emissions, FDI & GDP	Panel quantile regression	FDI→CO ₂ ↑
Sung et al. (2018)	CO ₂ emissions, FDI, GDP & fixed capital stock	Panel quantile regression-GMM	FDI→CO ₂ ↓
Ssali et al. (2019)	CO ₂ emissions FDI, GDP & fixed capital stock	ARDL-PMG	FDI→CO ₂ ↑
Nguyen (2018)	CO ₂ emissions, FDI, GDP & EC	ARDL-Granger causality	FDI↔ CO ₂ ↑

Table 3
EC and CO₂ emissions

Authors	Variables	Methodology	Relationship
Ameyaw and Yao (2018)	CO ₂ emissions, EC & GDP	ARDL-VECM	EC↔ CO ₂
Behera and Dash (2017b)	CO ₂ emissions, FDI & EC & GDP	Pedroni Cointegration	EC→CO ₂ ↑
Boutabba (2014)	CO ₂ emissions, EC, GDP & Trade	ARDL-VECM	EC→CO ₂ ↑
Dogan and Aslan (2017)	CO ₂ emissions, EC, real GDP	Cointegration test	EC↔ CO ₂
Kim (2019)	CO ₂ emissions, GDP & EC	Granger Causality	EC→CO ₂ ↑
Hwang and Yoo (2014)	CO ₂ emissions, EC & GDP	Granger Causality	EC↔ CO ₂
Leitão and Balogh (2020)	CO ₂ emissions, EC & GDP	Granger Causality	EC→CO ₂ ↑
Lu (2017)	CO ₂ emissions, EC & GDP	Granger Causality	EC→CO ₂ ↑
Abbasi et al. (2021)	CO ₂ emissions & EC	ARDL-VECM	EC↔ CO ₂
Saidi and Hammami (2015)	CO ₂ emissions, EC, GDP & FDI	GMM	EC→CO ₂ ↑
Shabestari (2018)	CO ₂ emissions, EC & fixed capital	VECM-Granger Causality	EC↔ CO ₂
Nguyen (2018)	CO ₂ emissions, EC, GDP & FDI	VECM- Granger Causality	EC→CO ₂ ↑
Note. → ← Represents unidirectional ↔ is bidirectional whereas ≠ presents no relationship ↑ ↓ represent an increase and decrease respectively.			

3. Econometric Model, Data Sources And Econometric Approach

Using a quadratic model as stated in Eq. (1), the study observed the relationship between GHG emissions, FDI, GDP, and EC in a few SAARC member states.

$$\ln CO_{2t} = \phi_1 + \phi_2 \ln GDP_t + \phi_3 \ln GDP_t^2 + \phi_4 FDI_t + \phi_5 TEC_t + \epsilon_t$$

1

where metric tones per capita is used as a unit to measure CO₂, current US dollars is used to measure GDP, FDI is calculated as a net inflow percentage of GDP, and British Thermal Units (BTU) per capita is used to measure total EC. The subscript *t* indicates the time period and ϕ_i is the intercept where $i = 1 \dots 5$. The error term is represented by ϵ . Except for total energy consumption, the time series data were captured from the database of the World Bank development indicator, 2021. The data on energy consumption comes from the World Energy Statistics 2021. All of the variables used in the regression model are converted to logarithms, which show the elasticity (or percentage change) of the dependent variable. The sign of the parameters ϕ_2 and ϕ_3 is predicted to be positive or negative based on the theory of the environmental Kuznets curve (EKC). At the primary stages of growth of any country, the positive sign of the coefficient ϕ_2 implies a positive association between $\ln CO_2$ and $\ln GDP$. Similarly, the nonlinear inverted U-shaped relationship between CO₂ emissions and GDP per capita is confirmed by the negative sign of the squared parameter ϕ_3 of the EKC. As a result, the presence of EKC for the panel is confirmed by the statistical significance of both the positive and negative signs of the concerned parameter. Furthermore, the sign ϕ_4 associated with FDI is used to test the legitimacy of the pollution halo hypothesis or the pollution haven hypothesis. The first hypothesis contends that FDI reduces GHG emissions, whereas the last hypothesis contends that FDI increases GHG emissions. As a result, the sign of the parameter ϕ_4 contributes to the validation of these two hypotheses. Generally, an intensification in energy consumption is projected to result in an escalation of CO₂ emissions as a result of increased economic activity; consequently, the expected sign of ϕ_5 is positive.

Cross-sectional dependence (CSD) is fairly prevalent and regularly encountered in practice when dealing with repeated cross-sectional data. It is self-evident to test for CSD before examining the stationary features of a time series or panel data. The use of unit root and cointegration methods could be adjusted by the CSD; otherwise, the estimate from the unit root and cointegration properties could be inconsistent (Silva et al. 2018). We used the lagrange multiplier (LM) test suggested by Breusch and Pagan (1980) and the CSD test suggested by Pesaran (2021) to regulate whether the panel data are cross-sectionally dependent or not. Both tests are calculated with cross-sectional independence as the null hypothesis and CSD as the alternative hypothesis. By assuming potential cross-sectional independence within the panel data, this work analyzed stationary qualities utilizing the second generation unit root tests such as cross-sectionally augmented dickey (CADF) and cross-sectionally Im-Pesaran-Shin (CIPS). Pearson (2007) suggested that the CADF and CIPS are superior to Levin, Lin and Chu (LLC) and Im Pesaran and Shin (IPS) panel unit root tests. The study used the Pedroni and Kao cointegration tests, as suggested by Pedroni (2004) and Kao (1999), to ensure that the investigated variables were cointegrated. Later, the study used ARDL to measure the long-run and short-run effects of our proposed variables on CO₂. The study also used the pooled mean group (PMG) estimator for further assessment. The Akaike information criterion (AIC) has been applied to select the best lag structure because it reduces the loss of degrees of freedom. It is also treated as the "parsimonious lag structure." In this case, the PMG estimator is utilized because it maintains long-run coefficient control across all cross-sections while allowing short-run coefficient diversity across all cross-sections. The ARDL model has some practical advantages, such as the ability to estimate short-and long-term consistent estimates simultaneously, regardless of whether the series is I(0) or I(1). With such a model and a modest sample size, reliable findings can be produced. Due to the presence of rich

dynamics, the problem of multicollinearity can be readily solved (Dougherty 2016). Finally, because all variables are expected to be endogenous, the ARDL model removes the endogeneity issues that plague the Engel-Granger technique (Seher et al. 2015). The ARDL (pq) model contains lag p used as the outcome and lag q used as the explanatory variable. This model was developed by Ssali et al. (2019) and it takes the following form:

$$y_{it} = \mu_i + \sum_{j=1}^p \lambda_{ij} y_{it-j} + \sum_{j=0}^q \delta_{ij}' x_{it-j} + \epsilon_{it}$$

2

where y_{it} denotes the outcome variable. The number of countries and time period used for analysis are symbolized by the subscript $i = 12 \dots N$ and $t = 12 \dots T$. The other subscript j is the number of cross-sections. The quantity of lags for the outcome and explanatory variables is expounded by p and q . The explanatory variables x_{it-j} represent a $m(\text{row}) \times n(\text{column})$ vector. The scalar vector is also expressed by λ_{ij} . The symbol δ_{ij}' shows the $m \times 1$ coefficient vector and ϵ_{ij} indicates the error term.

If there is cointegration between the variables under investigation, the ARDL model should be reformulated. In the ARDL model, cointegration could be a concern in short-run dynamics. To obtain a consistent estimate, the error correction term (ECT) should be added. The ECT is used to measure how quickly a dependent variable approaches long-run equilibrium while the independent variable changes. The ECT can be written like this:

$$\Delta y_{it} = \varphi_i (\Delta y_{it-1} - \tau_i' x_{it}) + \sum_{j=1}^{p-1} \lambda_{ij} \Delta y_{it-j} + \sum_{j=0}^{q-1} \delta_{ij}' \Delta x_{it-j} + \epsilon_{it}$$

3

where $\varphi_i = -(1 - \sum_{j=1}^p \lambda_{ij})$ and $\tau_i = \frac{\sum_{j=0}^q \delta_{ij}'}{\varphi_i}$. In Eq. (3) τ and δ_{ij}' and show the long-run association between outcome and explanatory variables. The symbol φ_i is a part of ECT and is likely to be non-positive or less than one. The presence of cointegration is indicated by a negative sign, whereas the pace of adjustment is indicated by a fraction less than one. If $\varphi_i = 0$ there is no confirmation of a long-run relationship (no cointegration). Therefore, by combining the ECT, our model follows Eq. (4), where CO_2 emission is the outcome variable, and other variables (GDP, GDP^2 , and FDI energy use) are the explanatory variables.

$$\Delta CO_{2i} = \alpha + \varphi_i (\Delta CO_{2i} - \tau_{1i}' GDP_{it} + \tau_{2i}' GDP_{it}^2 - \tau_{3i}' FDI_{it} - \tau_{4i}' TEC_{it}) + \sum_{j=1}^{p-1} \lambda_{ij} \Delta CO_{2i-j} + \sum_{j=0}^{q-1} \delta_{1ij}' \Delta GDP_{it-j} + \sum_{j=0}^{q-1} \delta_{2ij}' \Delta GDP_{it-j}^2 + \sum_{j=0}^{q-1} \delta_{3ij}'$$

4

While estimating Eq. (4), we chose the PMG estimator given by Pesaran et al. (1999) since it has various advantages over the others. For example, it accounts for differences in short-run coefficient intercepts and error variation among countries. Long-run estimates are similarly restricted by this estimator to being constant. According to Pesaran et al. (1999), the advantage of PMG is that it is robust to outliers as well as lag orders. The PMG has grown popular among researchers due to its application capacity (Baek and Choi 2017; Rafindadi et al. 2018b; Ssali et al. 2019; Yusuf et al. 2020). In order to justify the suitability of the pooling coefficient in the ARDL situation, we used Hausman poolability to diagnose the above-mentioned model. This diagnostic test checks if the null hypothesis of pooled long-run coefficients being identical for all cross-sections is true or not (Ssali et al. 2019). Finally, we applied the panel Granger causality test to measure the causality-based vector error correction's direction. The Granger causality test was done in two steps. The long-run relationship is estimated in the first phase in order to create an ECT for the second step. In the long run, an ECT is defined as one-period lagged residuals. The ECT sign specifies whether one or two variables are used to correct divergence from the long-run relationship. The VECM is also calculated using biased-corrected least square dummy variables (Bruno 2005). Boutabba (2014) defined the VECM as follows:

$$(1 - B) Y_{it} = \mu_{1it} + \sum_{i=1}^p (1 - B) [\lambda_{1it}] Y_{it-1} + \delta_{1it} [ECT_{it-1}] + \epsilon_{it}$$

5

where $i = 12 \dots N$ shows the country, $t = 12 \dots T$ presents the time, p indicates the lag length, $(1 - B)$ is the first difference operator, ϵ_{it} is treated as a serially uncorrelated error term and a finite covariate matrix, and ECT_{it-1} shows for lagged ECT. The VECM is used to capture both long-run and short-run Granger causality. The F-test of lagged explanatory factors may be used to determine short-run dynamics, while the t-statistics on the coefficient of lagged error term can be used to determine the significance of long-run contributing effects. Our VECM-based modified model is applied to test the way of the causality, and that can be written as follows:

$$\begin{bmatrix} \Delta \ln CO_{2it} \\ \Delta \ln GDP_{it} \\ \Delta \ln GDP_{it}^2 \\ \Delta \ln FDI_{it} \\ \Delta \ln TEC_{it} \end{bmatrix} = \begin{bmatrix} \mu_1 \\ \mu_2 \\ \mu_3 \\ \mu_4 \\ \mu_5 \end{bmatrix} + \sum_{i=1}^p \begin{bmatrix} \lambda_{11p} \lambda_{12p} \lambda_{13p} \lambda_{14p} \lambda_{15p} \\ \lambda_{21p} \lambda_{22p} \lambda_{23p} \lambda_{24p} \lambda_{25p} \\ \lambda_{31p} \lambda_{32p} \lambda_{33p} \lambda_{34p} \lambda_{35p} \\ \lambda_{41p} \lambda_{42p} \lambda_{43p} \lambda_{44p} \lambda_{45p} \\ \lambda_{51p} \lambda_{52p} \lambda_{53p} \lambda_{54p} \lambda_{55p} \end{bmatrix} \begin{bmatrix} \Delta \ln CO_{2it-p} \\ \Delta \ln GDP_{it-p} \\ \Delta \ln GDP_{it-p}^2 \\ \Delta \ln FDI_{it-p} \\ \Delta \ln TEC_{it-p} \end{bmatrix} + \begin{bmatrix} \delta_1 \\ \delta_2 \\ \delta_3 \\ \delta_4 \\ \delta_5 \end{bmatrix} ECT_{it-1} + \begin{bmatrix} \epsilon_{1it} \\ \epsilon_{2it} \\ \epsilon_{3it} \\ \epsilon_{4it} \\ \epsilon_{5it} \end{bmatrix} \quad (6)$$

4. Result And Discussion

4.1 CSD test

We run Breusch-Pagan LM and Pesaran CSD tests before applying the unit root test. The CSD result for our model is shown in Table 4. The null hypothesis of cross-sectional independence is rejected for our model based on the various probability values. This means that the CSD test confirms that the panel series is cross-sectionally dependent. The unit root test is used in this study to account for cross-sectional dependence in the estimation process. Additionally, we apply the CADF and CIPS tests in the next step because traditional unit root tests are no longer viable in the presence of CSD and fail to account for cross-sectional dependence in the estimating process.

Table 4
Estimation of Breusch -Pagan LM and Pesaran CSD tests

Tests	Statistics
Breusch -Pagan LM	80.215***
<i>P-Value</i>	0.000
Pesaran CSD	1.790***
<i>P-Value</i>	0.001
Note. The asterisk *** **and * specify statistical significance levels at 1% 5% and 10% .	

4.2 Panel unit root test

To obtain the stationary property and analyze the sequence of integration amongst examining panel time series, this study uses CADF and CIPS unit root tests rather than the traditional unit root test. This is because the CADF and CIPS unit root tests produce valid results in the presence of CSD. As a result, Table 5 shows the outcomes of these two tests. The CADF and CIPS tests reveal that all variables except lnFDI have unit root (non-stationary) at levels, as indicated in Table 5. However, following the initial difference, they become stationary. Given the substantial evidence for a common sequence of integration among the variables under examination, I (1). After the first difference, the CADF and CIPS tests reject the null hypothesis that the variables are non-stationary, and the involved variables demonstrate the stationary property and I (1). Because the variables are stable at the first difference, the cointegration test is used to see if there is a long-term relationship between them.

Table 5
Results of unit root tests for CADF and CIPS

Variables	Level		1st difference		Order of integration
	Intercept	Intercept & trend	Intercept	Intercept & trend	
CADF test					
lnCO ₂	-1.385	-1.945	-3.977***	-4.214***	I(1)
lnGDP	-2.295	-2.601	-4.026***	-4.140***	I(1)
lnGDP ²	-2.295	-2.406	-3.397***	-3.413***	I(1)
lnFDI	-3.110*	-2.937*	-4.527***	-4.485***	I(0)/ I(1)
lnTEC	-2.509	-3.322	-4.988***	-5.176***	I(1)
CIPS test					
lnCO ₂	-1.736	-2.287	-6.006***	-6.154***	I(1)
lnGDP	-2.263	-2.685	-5.626***	-5.796***	I(1)
lnGDP ²	-2.027	-2.453	-5.626***	-5.796***	I(1)
lnFDI	-3.413	-3.301	-5.604***	-5.714***	I(1)
lnTEC	-2.491	-3.275	-5.884***	-6.077***	I(1)
Note. The Akaike Information Criterion is used to determine the optimal lags.					

The asterisk *** **and * specify statistical significance levels at 1% 5% and 10% .

4.3 Panel cointegration test

The cointegration tests of Pedroni (2004) and Kao (1999) were utilized to confirm the existence of cointegration. Pedroni's panel cointegration test results for several models are shown in Table 6, along with seven different test statistics. At the 1%, 5%, and 10% levels of significance, the majority of test findings, both panel-based and group-based, indicated evidence of panel cointegration among the variables. As a result, the null hypothesis of no cointegration is rejected at a different level of significance for the majority of the test statistics. By using the Kao (1999) cointegration test, the homogenous slope coefficient over the cross-section is also shown in Table 6. This test revealed that the investigating variables are cointegrated with a heterogeneous slope by rejecting the null hypothesis of no cointegration with a homogenous slope coefficient at a 10% level of significance. Both tests are statistically significant, indicating that the panel variables in the models have a long-run cointegrating relationship.

Table 6
Result of cointegration test for Pedoni and and Kao

<i>Pedroni 2004</i>	Statistics	Weighted Statistics
Common AR coefficient (within dimensions)		
Panel v-statistic	-0.124	-0.617
Panel rho-statistic	-2.73**	-2.456**
Panel PP-statistic	-3.686**	-3.349**
Panel ADF-statistic	-3.640**	-3.321**
Common AR coefficient (within dimensions)		
Group rho-statistic	-1.60***	
Group pp-statistic	-3.319**	
Group ADF-statistic	-3.104***	
Kao		
ADF	-2.60**	
Note. The asterisk *** **and * specify statistical significance levels at 1% 5% and 10% .		

4.4 ARDL long-run and short-run elasticities using PMG

To estimate long-run and short-run estimates of CO₂ emissions, GDP, FDI, and ECe, this study used the PMG estimator using ARDL. Table 7 shows the findings of the PMG estimator. The Chi-squared test statistics of the Hausman test have a value of 72.425 with a connecting p-value of 0.377, according to the ARDL model using the PMG estimator. This p-value is greater than 0.05, indicating that the null hypothesis cannot be rejected and demonstrating that long-run coefficients for all cross-sections are equal. The null hypothesis is rejected, indicating that the homogeneity restriction is valid and that the PMG estimator is

more efficient. With an appropriate sign, the coefficient of lag ECT is statistically significant (the negative sign and less than unity). Any divergence from the long-run equilibrium of GDP per capita in one year is rectified by around 72 percent the following year, according to the coefficient of -0.715. Both the short-run and long-run coefficients of $\ln\text{GDP}$ are positive and significant at a 5% level. The coefficient of $\ln\text{GDP}^2$ on the other hand, as expected, reveals a negative association and is significant in both the short-and long-run. The presence of an inverted U-shaped relationship with CO_2 emissions is revealed by the statistical significance of both linear and nonlinear factors of GDP per capita. The conclusion shows that a 1% increase in GDP per capita will result in a 0.68 percent increase in CO_2 emissions per capita, whereas the negative nonlinear term appears to confirm the delinking of CO_2 emissions by 0.024 percent with a higher level of GDP at 5% in the long-run. This positive and negative relationship holds true for estimates of short-run coefficients. These findings are consistent with the EKC hypothesis, which claims that economic growth is both a cause and a clarification for the rising GHG emissions. As a result, SAARC member states would not be afraid to pursue their economic growth strategies because, in the long run, economic growth would address the environmental challenges that arose during the primary stages of growth. This outcome backs up the conclusions of the previous studies by Nicholas and Ozturk 2015; Pata 2018; Rana and Sharma 2019; Ssali et al. 2019.

Apart from $\ln\text{FDI}$, the other variable such as $\ln\text{TEC}$ is statistically significant. In the medium and long-run, a 1% increase in energy use results in 0.287 percent and 0.046 percent increases in CO_2 emissions. Ssali et al. (2019) carried out research in a few selected Sub-African countries and revealed that energy use increases GHG emissions. Such a relationship is also consistent with the findings of Ahmed et al. (2017) for South Asia, Solarin et al. (2018) for 80 developing nations, Apergis & Payne (2015) for 11 South American countries, and Pata (2018) for Turkey.

Table 7
ARDL Long-run and short-run elasticities for PMG

$\Delta \ln\text{CO}_2$ (12222)	
Long-run	
$\Delta \ln\text{GDP}$	0.680**
$\Delta \ln\text{GDP}^2$	-0.024**
$\Delta \ln\text{FDI}$	-1.753
$\Delta \ln\text{TEC}$	0.046**
ECT	-0.715***
Short-run	
$\Delta \ln\text{CO}_2$	
$\Delta \ln\text{GDP}$	0.245**
$\Delta \ln\text{GDP}^2$	-0.022**
$\Delta \ln\text{FDI}$	0.367
$\Delta \ln\text{TEC}$	0.287*
Hausman	72.425
P-value	0.377
Note. The asterisk *** **and * specify statistical significance levels at 1% 5% and 10% .	

4.5 Country-specific ARDL model with PMG estimator

For each cross section, we also run the ARDL model using the PMG estimator. In order to be certain about the presence or lack of autocorrelation, we used the B-G LM test and the Autoregressive Conditional Heteroskedasticity (ARCH) test to evaluate heteroscedasticity. In addition to testing the model's stability, we ran cumulative CUSUM and CUSUMSQ tests on each cross-section. The serial correlation (B-G LM test) and heteroscedasticity (ARCH test) results in Table 8 show that these ARDL models are free from the autocorrelation and heteroscedastic problems. The estimated results of CUSUM and CUSUMSQ corroborate the stability of these models. The EKC can be verified by examining the long-run elasticity characteristics of two variables: $\Delta \ln\text{GDP}$ and $\Delta \ln\text{GDP}^2$. The long-run coefficients of $\Delta \ln\text{GDP}$ and $\Delta \ln\text{GDP}^2$ are statistically significant, with a positive and negative sign for Pakistan and Sri Lanka. Both the results for Pakistan and Sri Lanka support the EKC hypothesis and economic expansion for CO_2 emissions in Pakistan and Sri Lanka. On the contrary, the anticipated parameters for $\Delta \ln\text{FDI}$, has a favourable influence on CO_2 emissions in Bangladesh and Nepal but has a negative impact in India, Pakistan, and Sri Lanka. The findings upkeep the presence of the pollution haven hypothesis in Bangladesh and Nepal as well. Table 8 shows that the $\Delta \ln\text{TEC}$ has a large favourable impact on CO_2 emissions in all nations.

Table 8
Country specific ARDL PMG estimator

Dependent variable	Bangladesh	India	Nepal	Pakistan	Sri-Lanka
	$\Delta \ln CO_2$				
	(3 21 20)	(4 2 1 3 3)	(1 4 4 0 3)	(3 4 1 4 1)	(2 0 1 1 0)
Long Run					
$\Delta \ln GDP$	1.971**	-0.238**	3.596	0.154***	0.333**
$\Delta \ln GDP^2$	0.150**	0.020**	-0.315	-0.405***	-0.020**
$\Delta \ln FDI$	2.230**	-0.406	4.421**	-0.168	-0.544
$\Delta \ln TEC$	0.705***	0.662***	0.743***	0.442**	1.339**
ECT	-0.593*	-0.425**	-0.836***	-0.574***	-0.337**
Adj. R ²	0.820	0.797	0.726	0.890	0.790
Short Run					
$\Delta \ln GDP$	1.798**	1.679**	3.084	4.015**	5.489**
$\Delta \ln GDP^2$	-0.158**	-0.130	-0.257	-0.330**	-0.390**
$\Delta \ln FDI$	0.228	-0.174	3.699*	-0.008	-0.060
$\Delta \ln TEC$	0.417***	-0.323	0.714**	-0.301**	0.471***
Diagnostic					
B-G LM Test	0.398	1.236	0.645	0.811	0.514
ARCH	0.125	0.193	0.404	0.339	2.959
CUSUM	Stable	Stable	Stable	Stable	Stable
CUSUMSQ	Stable	Stable	Stable	Stable	Stable
Note. The asterisk *** **and * specify statistical significance levels at 1% 5% and 10% .					

4.6 Panel Granger causality test

After applying the ARDL approach to measure the direction of the effects, the VECM-based Granger causality test was used to evaluate the short-and long-run directions of causal effects. Table 9 shows the results of the panel Granger causality test. The short-run dynamics based on F-statistics imply unidirectional causality. Likewise, the statistical significance of lagged ECT indicates there is a long-run linkage of CO₂, FDI, TEC, and GDP. Panel Granger causality findings show unidirectional Granger causality between energy consumption and GHG emissions, FDI and GHG emissions, and energy consumption and GHG emissions. On the other hand, four bidirectional casualities such as GHG emissions and energy use, GHG emissions and FDI, energy use and GDP, and FDI and energy use have been discovered. The ECT coefficients in GHG emissions and FDI are significant, implying that there are two long-run panel causal links between energy use FDI and GDP to GHG emissions as well as energy use and GDP to FDI.

Table 9
The result of Panel Granger causality test

Dependent variable	Source of causation (Independent variables)					
	Short-run					Long Run
	$\Delta \ln CO_2$	$\Delta \ln GDP$	$\Delta \ln GDP^2$	$\Delta \ln FDI$	$\Delta \ln TEC$	ECT
	F statistic					t-statistics
$\Delta \ln CO_2$	—	2.424*	2.406*	0.046*	5.423**	-0.001*
$\Delta \ln GDP$	0.141	—	1.350	1.552	0.318*	-0.005
$\Delta \ln GDP^2$	0.127	1.542	—	1.732	0.361	-0.08
$\Delta \ln FDI$	5.273**	7.867	7.270***	—	2.405**	0.006***
$\Delta \ln TEC$	7.462***	1.075	0.837	2.211	—	0.003
Note. The asterisk *** **and * specify statistical significance levels at 1% 5% and 10% .						

5. Conclusion And Policy Implication

Climate change is attracting traction, as is the link between pollution and GDP, FDI, and energy consumption. The EKC hypothesis can be applied to assess the link between ecological impurity and economic growth. Furthermore, rising energy demand and FDI inflows may wreak havoc on developing countries' environmental quality. However, there is continuing discussion over the impact of FDI and energy consumption on environmental norms. Over the last few decades, the trade-off between energy expansion and FDI emissions has also been a hotly disputed topic. Therefore, these variables are significant because of the assorted roles they play in designing policies for reducing CO₂ emissions. It is also rational for policymakers to set suitable plans to curb CO₂ emissions. Thus, in the context of SAARC countries, this study tried to bridge this gap by studying the causal link between these factors under a unified framework. SAARC member countries' remarkable economic development and FDI interest pose various questions among policymakers. For instance, have the SAARC countries justified the principle of EKC in their environment? Does FDI lead to or clean the environment in this region? Is there a link between economic indicators like GDP, FDI energy consumption, and CO₂ emissions? Given the outstanding economic growth rate, verifying and assessing the relationship between energy use and inward FDI into SAARC countries is essential. This research examines five SAARC member states, including Bangladesh, India, Nepal, Pakistan, and Sri Lanka, using panel data from 1980 to 2016.

The empirical investigation begins with two CSD tests to determine whether the panel data series is cross-sectionally independent. The CSD tests show that there is cross-sectional dependence among the panel members. Because the unit root tests for the second stage are sensitive to cross-sectional dependence to authenticate the stationary qualities of a time series, cross-sectional dependence tests are reasonable. Given that the current study continues to use CADF and CIPS, which use cross-sectional dependence tests instead of traditional unit root tests in the estimating procedure. After having the first difference, the CADF and CIPS results show that variables confirm the stationary property and standard order of integration I(1). Because the variables are stationary at the first difference, the cointegration test is used to determine whether or not there is cointegration. Pedroni (2004) and the Kao cointegration test were used in this investigation. The statistical significance of both tests indicates that the panel variables in the models are cointegrated. The ARDL model was then used in the study, which was based on the PMG estimator. In the long run, a 1% increase in GDP per capita results in a 0.68 percent increase in CO₂ emissions per capita, according to our estimates. Furthermore, a 1% increase in energy consumption results in increases in CO₂ emissions of 0.287 percent and 0.046 percent in the medium and long run, respectively. The PMG estimates of GDP both in the short-and long-run indicate that GDP has a significant positive impact on GHG emissions, while GDP² negatively affects GHG emissions. The presence of an inverted U-shaped relationship with CO₂ emissions is revealed by the statistical significance of both linear and nonlinear factors of GDP per capita. Our findings also show that the error correction coefficient for GHG emissions reaches long-run equilibrium in the following year at a rate of 4.6 percent. For Pakistan and Sri Lanka, country-specific ARDL PMG estimations support the EKC hypothesis. On the other hand, FDI has been found to have a favourable influence on CO₂ emissions in Bangladesh and Nepal but a negative impact in India, Pakistan, and Sri Lanka. As a result, the pollution haven theory has been discovered for Bangladesh and Nepal, while the pollution halo hypothesis has been found to be true for India, Pakistan, and Sri Lanka. Energy use has a substantial positive impact on CO₂ emissions for all countries.

Table 9 depicts the direction of the causal relationship between our proposed variables. The VECM-based Granger causality test shows that unidirectional Granger causation exists between GDP and GHG emissions, FDI and GHG emissions, and energy use and GHG emissions. Similarly, there are four bidirectional causalities between GHG emissions and energy use, GHG emissions and FDI, energy usage and GDP, as well as FDI and energy use, which have been detected. However, there is no causal association between GDP and FDI. The statistical significance of ECT suggests that there are two long-run panel causal links between energy use FDI and GDP to GHG emissions, as well as between energy use GDP and GHG emissions to FDI.

The present study has gone some way towards enhancing our understanding of environmental pollution and four vibrant economic variables. It's important to remember that any changes in energy and FDI policies that reduce CO₂ emissions while maintaining economic growth must take into account variables other than the underlying variables in this study. This research can be expanded to include deforestation, institutional quality, rural development concerns, and other environmental variables in the context of SAARC countries as part of a prospective research opportunity. Furthermore, the impact of renewable and non-renewable energy use on CO₂ emissions by country could be a fascinating issue for additional research.

The generalisability of the present study is subjected to certain limitations. For instance, the study's scope was limited to looking into the causal relationship between CO₂ emissions, GDP, FDI, and energy use in SAARC countries. Despite the fact that SAARC is made up of eight countries, this study only looks at five of them, based on data from two different sources. Furthermore, due to a lack of data, this study only covers a small number of observations and a short time period (1980-2016). Another potential flaw in this study is that it does not account for the structural breaks in individual data series when performing cointegration analysis. Finally, there is a limitation that is linked to the omitted variable bias. In order to avoid omitted variable bias, similar studies include variables that significantly contribute to CO₂ emissions and GDP. However, it was not done for this study, and it may be improved by adding more factors.

Our study's outcomes have a number of important insights for future practice. SAARC countries must change their investment strategies to include renewable energy sources in order to achieve economic progress. However, because they are energy-dependent economies, there must be a balance between economic growth and energy use. Alternative energy sources, such as wind energy, hydropower, nuclear energy, and solar energy, should be prioritized. This can be accomplished through expanding and strengthening renewable energy supplies in the targeted countries, as well as increasing energy efficiency around the globe. To counteract GHG emissions, green investment should be encouraged, and clean industries using green technology should be prioritized in these selected countries. Any plan that encourages current polluting industries to move to cleaner technology will have a particularly positive impact on the implementation of policies aimed at lowering GHG emissions. Furthermore, increased public awareness of the benefits of green technology and the environment would hasten the reduction of GHG emissions.

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Competing Interest

The authors declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

Availability of Data and Materials

The datasets used during the current study are available from the corresponding author on reasonable ground and request.

Ethical Approval and Consent to Participate

Not applicable.

Authors Contributions

All authors contributed to the study conception and design. Material preparation, data collection and analysis were performed by Md. Nur Mozahid and Sharmin Akter. The first draft of the manuscript was written by Md. Nur Mozahid and the final draft of the manuscript was written by Md. Hafiz Iqbal. All authors read and approved the final manuscript.

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