Trade Liberalization, Fossil Fuel Consumption, and Carbon Intensity: Evidence from South Asian Countries

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ABSTRACT

Trade liberalization has accelerated economic integration across South Asia, but its environmental consequences remain a growing concern because expanding production, transportation, and industrial activity continue to rely substantially on fossil fuels. This study examines the effect of trade liberalization on carbon intensity and investigates whether fossil fuel consumption serves as a mediating transmission channel. Using a balanced panel of seven South Asian economies from 1990 to 2023, the study employs second-generation panel techniques, with CS-ARDL as the principal estimator. CCEMG and AMG estimators are used for robustness, instrumental-variable estimation addresses potential endogeneity, and quantile regression captures distributional heterogeneity. The findings show that trade liberalization significantly increases both fossil fuel consumption and carbon intensity in the long run. Economic growth, foreign direct investment, industrialization, and urbanization exert positive effects, whereas renewable energy consumption reduces both outcomes. Quantile results further indicate that the positive association of trade liberalization becomes larger at higher conditional quantiles. Most importantly, the Sobel and bootstrap tests confirm that fossil fuel consumption partially mediates the relationship between trade liberalization and carbon intensity. The findings highlight the importance of cleaner energy systems, renewable energy expansion, and low-carbon production strategies for reconciling trade integration with environmental sustainability in South Asia.

Keywords: Trade liberalization; Fossil fuel consumption; Carbon intensity; Mediation analysis; South Asia

INTRODUCTION

Trade liberalization has become an important component of economic reform and development strategies, particularly in developing economies seeking deeper integration into international markets. Reductions in tariff and non-tariff barriers can expand market access, improve resource allocation, strengthen competition, stimulate investment, and facilitate the international diffusion of knowledge and technology. These mechanisms can generate productivity and economic-growth benefits; however, trade expansion can simultaneously increase production, transportation, industrial activity, and energy demand. Consequently, the economic benefits associated with international integration may be accompanied by environmental costs, particularly in economies where production and transportation systems remain highly dependent on conventional energy sources (Frankel & Romer, 1999; Wacziarg & Welch, 2008; Antweiler et al., 2001). This trade-off has made the environmental consequences of trade liberalization an increasingly important issue for developing economies pursuing both economic integration and sustainable development.

The theoretical effect of trade liberalization on environmental quality is inherently ambiguous. Grossman and Krueger (1991) and Antweiler et al. (2001) explain the trade–environment relationship through scale, composition, and technique effects. The scale effect suggests that trade-induced expansion of production increases resource and energy consumption and can therefore intensify environmental pressure. The composition effect arises when international specialization changes the sectoral structure of production, with environmental consequences depending on whether expanding industries are relatively carbon intensive or environmentally efficient. In contrast, the technique effect suggests that international integration may improve environmental performance by facilitating technological diffusion, productivity improvements, and access to cleaner production technologies. The overall environmental effect therefore depends on the relative strength of these competing channels (Grossman & Krueger, 1991; Antweiler et al., 2001; Copeland & Taylor, 2004).

Energy consumption represents a particularly important channel through which these trade effects can influence environmental performance. Greater international integration can stimulate manufacturing, freight transportation, logistics, infrastructure, and export-oriented production, thereby increasing energy requirements. Cole (2006) finds that trade liberalization tends to increase energy use for the mean country in his sample, while Ghani (2012) demonstrates that the trade liberalization–energy relationship can vary with countries' development conditions. This mechanism is especially relevant to South Asia, where expanding trade and structural transformation coexist with substantial reliance on conventional energy. Rahman (2024) provides direct regional evidence that trade development is related to fossil fuel consumption, although the effects differ across South Asian countries. These findings suggest that the environmental consequences of trade integration cannot be fully understood without considering the energy structure supporting trade-related economic activity.

The composition of energy consumption is particularly important because fossil fuels are directly associated with carbon emissions. Coal, oil, and natural gas continue to support industrial production, transportation, electricity generation, and infrastructure development, but their combustion increases the carbon burden of economic activity. This study therefore focuses on carbon intensity, which measures carbon emissions relative to economic output rather than simply measuring the absolute quantity of emissions. Carbon intensity provides an indication of whether production is becoming more or less carbon efficient as an economy develops. Wang and Wang (2021), using data for 104 countries and regions, identify significant and heterogeneous effects of trade openness on carbon intensity, including an inverted-U-shaped relationship and an important conditioning role for FDI. This distinction is particularly important for rapidly developing economies because aggregate emissions may increase with economic growth even when the carbon efficiency of production improves (Grossman & Krueger, 1995; Stern, 2004; Wang & Wang, 2021).

Despite the extensive literature on international trade, energy consumption, and environmental degradation, an important research problem and gap remains. Much of the trade–environment literature examines the direct relationship between trade openness and aggregate or per-capita CO_2 emissions, while trade-energy studies investigate whether international integration changes energy demand. Energy consumption, in turn, is generally incorporated into environmental models as an independent explanatory variable. Consequently, these strands of literature provide limited evidence on whether they form a sequential mechanism through which trade liberalization changes environmental performance (Sadorsky, 2011; Shahbaz et al., 2017; Rahman, 2024). Regional evidence showing that trade development affects fossil fuel consumption further strengthens the case for examining this transmission mechanism explicitly. The existing literature therefore leaves an important question insufficiently addressed: does fossil fuel consumption transmit part of the effect of trade liberalization to carbon intensity?

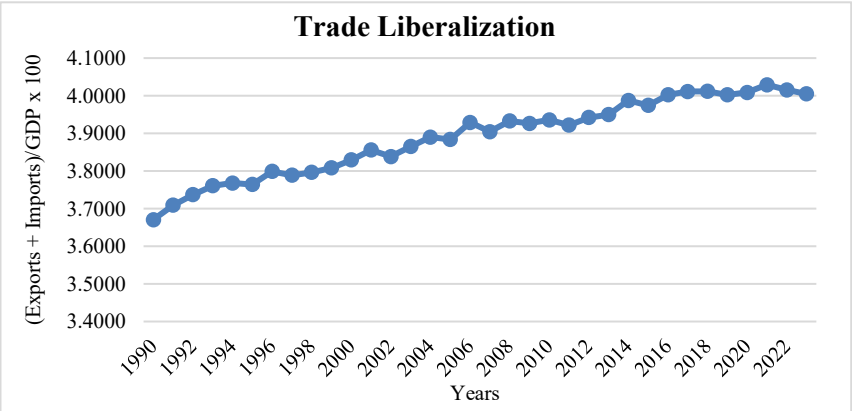


Figure 1: Trend of Trade Liberalization

Figure 1 illustrates the trend of trade liberalization over the period 1990-2023, measured by the ratio of total trade (exports plus imports) to GDP. The figure shows a generally upward trend in trade liberalization throughout the study period, although some short-term fluctuations are evident. The indicator increases from approximately 3.67 in 1990 to around 3.80 by the late 1990s, suggesting a gradual expansion in trade openness

during the early part of the sample. This upward movement continues during the 2000s, with temporary declines in some years, indicating that the process of international trade integration was not completely unifor-

m. From the early 2010s onward, trade liberalization rises further and remains relatively high, reaching approximately 4.00 or above during the late 2010s and early 2020s. A small decline is visible toward the end of the period, but the overall level remains substantially above that observed in the early 1990s. Overall, the figure indicates that the selected economies became progressively more integrated into international trade over the study period. This sustained increase in trade activity provides an important basis for examining whether greater trade liberalization has been accompanied by changes in fossil fuel consumption and carbon intensity.

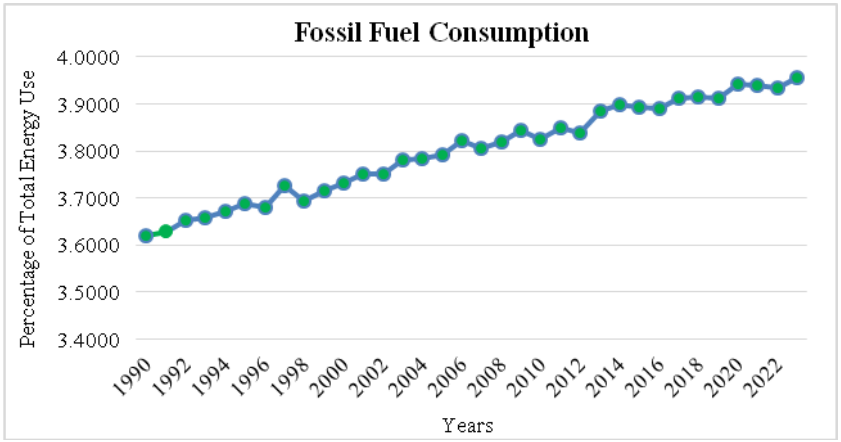


Figure 2: Trend of Fossil Fuel Consumption

Figure 2 presents the trend of fossil fuel consumption over the period 1990–2023, measured as a percentage of total energy use. The figure shows a clear and persistent upward trend throughout the study period, increasing from approximately 3.62 in 1990 to about 3.95 in 2023. During the 1990s, fossil fuel consumption increased gradually, although minor fluctuations occurred around 1996–1998. The upward movement continued during the 2000s, with temporary declines in a few years, followed by a more noticeable increase after 2012. From around 2014 onward, fossil fuel consumption remained at relatively high levels, with only small year-to-year fluctuations, before reaching its highest level near the end of the sample period. Overall, the trend indicates a growing dependence on fossil fuels over the study period. This persistent increase is particularly relevant to the present study because greater fossil fuel consumption may constitute an important mechanism through which expanding economic and trade activities influence carbon intensity.

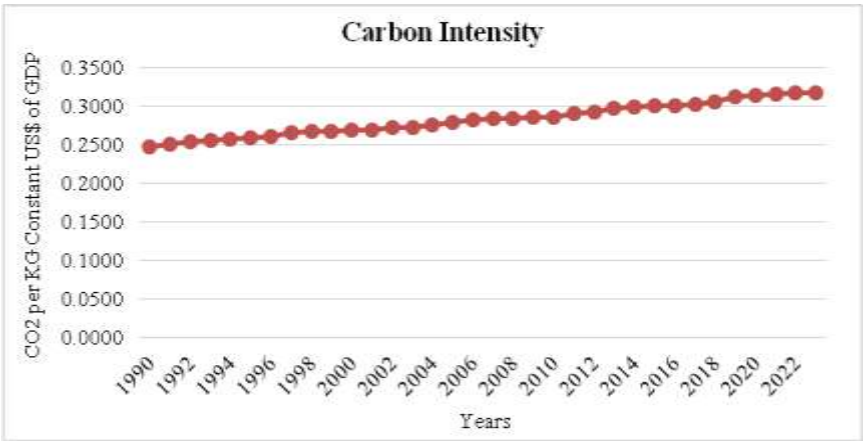


Figure 3: Trend of Carbon Intensity

Figure 3 presents the trend of carbon intensity over the period 1990–2023, measured as CO_2 emissions per unit of GDP in constant US dollars. The figure demonstrates a clear and gradual upward trend in carbon intensity, increasing from approximately 0.245 in 1990 to about 0.317 in 2023. During the 1990s and early 2000s, carbon intensity increased steadily with only minor fluctuations. The upward movement continued during the

mid-2000s, followed by a relatively stable period around 2008–2011. From 2012 onward, carbon intensity generally increased further, with a particularly noticeable rise after 2018, reaching its highest level toward the end of the study period. Overall, the trend suggests that carbon emissions per unit of economic output increased over time, indicating that improvements in economic output were not accompanied by a corresponding reduction in carbon intensity. The simultaneous upward patterns in trade liberalization, fossil fuel consumption, and carbon intensity provide descriptive motivation for empirically examining whether trade liberalization influences carbon intensity directly and indirectly through fossil fuel consumption.

To address this gap, the present study develops an integrated trade–fossil energy–carbon intensity framework in which fossil fuel consumption serves as a mediating variable. The proposed mechanism suggests that trade liberalization expands production, industrial activity, transportation, and logistics, thereby increasing energy requirements. Where this additional demand is satisfied primarily through fossil fuels, carbon intensity can subsequently increase. At the same time, trade liberalization may continue to affect carbon intensity directly through industrial specialization, foreign investment, technological change, transportation, and production efficiency. This framework is consistent with evidence that trade liberalization can influence national energy use and that the trade–carbon intensity relationship varies across economic conditions (Cole, 2006; Ghani, 2012; Wang & Wang, 2021). It therefore moves beyond determining whether trade affects environmental performance toward identifying how part of that effect is transmitted through the energy system.

The study is significant from theoretical, empirical, methodological, and policy perspectives. Theoretically, it connects international trade, energy economics, and environmental economics within a unified analytical framework. Empirically, it examines seven South Asian economies over 1990–2023, providing a balanced panel of 238 country-year observations. The study incorporates economic growth and its squared term, foreign direct investment, industrialization, urbanization, and renewable energy consumption to account for relevant structural influences. Methodologically, it recognizes cross-sectional dependence and heterogeneity among regional economies and therefore employs second-generation panel techniques, with CS-ARDL serving as the principal estimator and FMOLS, DOLS, CCEMG, and AMG providing complementary robustness evidence. These methodological choices are particularly relevant because ignoring common shocks and heterogeneous country responses can lead to unreliable panel estimates (Pesaran, 2006; Chudik & Pesaran, 2015; Ditzen, 2018).

This study makes several important contributions. First, unlike studies that examine trade–energy and trade–environment relationships separately, it integrates trade liberalization, fossil fuel consumption, and carbon intensity into a unified empirical framework. Second, it treats fossil fuel consumption as a mediator, rather than simply another explanatory variable, enabling identification of an explicit energy-based transmission mechanism. Third, it employs carbon intensity as the principal environmental outcome, thereby emphasizing the carbon efficiency of economic production rather than absolute emissions alone. Finally, the study combines mediation regression with the Sobel test and bootstrap confidence intervals to evaluate the statistical significance of the indirect effect. Mediation analysis is particularly useful for moving from simple associations toward understanding the mechanism connecting an explanatory variable with an outcome, while bootstrap procedures provide direct inference for the indirect effect (Baron & Kenny, 1986; Preacher & Hayes, 2004; Hayes & Scharkow, 2013).

LITERATURE REVIEW AND HYPOTHESIS DEVELOPMENT

2.1 Trade Liberalization and Fossil Fuel Consumption

The relationship between trade liberalization and energy consumption is primarily explained through the scale, composition, and technique effects of international trade. The scale effect suggests that greater trade integration expands production, transportation, and industrial activity, thereby increasing energy demand. The composition effect arises when trade changes the sectoral structure of an economy, particularly when specialization shifts toward energy-intensive industries. Conversely, the technique effect may reduce energy intensity by facilitating technological diffusion, productivity improvements, and access to energy-efficient capital equipment. Consequently, the net effect of trade liberalization on energy consumption depends on the relative strength of these mechanisms (Antweiler et al., 2001; Cole, 2006; Ghani, 2012).

Empirical evidence generally supports an important trade–energy nexus, although its magnitude varies across economies. Cole (2006) finds that trade liberalization can increase national energy use through changes in economic scale and industrial composition, while Ghani (2012) reports that the effect varies according to countries' development conditions. More directly, Rahman (2024) finds that trade development influences fossil fuel consumption across South Asian economies, although substantial country-level heterogeneity exists. This is particularly relevant because trade-related manufacturing, transportation, and infrastructure expansion can generate additional demand for coal, oil, and natural gas when cleaner energy alternatives are insufficiently developed.

Recent research continues to demonstrate the importance of the trade–energy relationship in South Asia. Begum et al. (2026), using six South Asian economies over 1990–2023, show that energy intensity, economic growth, urbanization, renewable energy, and trade openness jointly shape the region's emissions trajectory. Similarly, Hassan et al. (2025) find significant long-run relationships among trade openness, industrialization, renewable energy consumption, urbanization, and environmental pollution in South Asia, while their analysis explicitly accounts for cross-sectional dependence. Recent Asian evidence also shows that trade is interconnected with the transition toward renewable energy, indicating that international integration can influence not only the quantity but also the composition of energy consumption.

For South Asian economies, however, the environmental benefits of trade-related technological diffusion may be constrained when additional production and transportation continue to rely heavily on conventional energy. Trade liberalization may therefore expand economic activity faster than the energy system transitions toward cleaner alternatives. This provides a theoretical basis for expecting a positive relationship between trade liberalization and fossil fuel consumption, consistent with the trade–energy mechanism developed in the present study.

H1: *Trade liberalization has a positive and significant effect on fossil fuel consumption in South Asian economies.*

2.2 Trade Liberalization and Carbon Intensity

A substantial literature examines the environmental consequences of international trade, but the findings remain mixed. Greater trade openness may increase environmental pressure by expanding economic activity and encouraging specialization in pollution-intensive production. Conversely, access to cleaner technologies, international competition, and productivity improvements can reduce the environmental burden of production. Shahbaz et al. (2017) demonstrate that the trade openness–carbon emissions relationship varies across countries and levels of trade integration, reinforcing the argument that the environmental effects of trade are heterogeneous rather than universal.

Carbon intensity provides a particularly useful perspective because it captures emissions relative to economic output rather than absolute emissions. Wang and Wang (2021), using 104 countries and regions, find a nonlinear relationship between trade openness and carbon intensity and demonstrate substantial heterogeneity across income groups. Their results also indicate that FDI conditions the trade–carbon intensity relationship, emphasizing that trade operates alongside investment and structural transformation rather than in isolation. Thus, the environmental effect of international integration can vary depending on development level, production structure, technological capacity, and the composition of energy use.

Recent South Asian evidence largely reinforces the environmental relevance of trade openness. Hassan et al. (2025) report that trade openness, industrialization, and urbanization increase environmental pollution in South Asia, whereas renewable energy consumption improves environmental quality. Islam (2026), examining five SAARC economies from 1991 to 2023, similarly finds that trade, energy consumption, urbanization, and economic growth contribute positively to long-run CO_2 emissions. At the country level, Huang et al. (2025) find that trade openness increases environmental pollution in Pakistan, whereas renewable energy helps mitigate the environmental consequences associated with greater international integration. These findings suggest that the environmental consequences of trade liberalization in South Asia remain strongly conditioned

by production and energy structures. Where trade-induced expansion is supported by carbon-intensive energy, greater integration can increase emissions relative to economic output. Accordingly, the study proposes:

H2: *Trade liberalization has a positive and significant effect on carbon intensity in South Asian economies.*

2.3 Fossil Fuel Consumption and Carbon Intensity

Energy composition is a fundamental determinant of environmental performance. Fossil fuels generate carbon emissions through the combustion of coal, petroleum, and natural gas used in electricity generation, manufacturing, transportation, and other productive activities. Consequently, economies characterized by greater fossil-energy dependence are likely to experience greater carbon pressure unless productivity and technological improvements offset the emissions generated by additional energy consumption. Renewable energy can produce the opposite effect by substituting for conventional energy and reducing the carbon content of production (Rahman & Velayutham, 2020; Murshed et al., 2021).

Recent evidence supports the importance of the energy mix for South Asian environmental sustainability. Begum et al. (2026) identify energy intensity as an important determinant of emissions in South Asia and emphasize the need for renewable-energy expansion and improvements in energy efficiency. Brohi et al. (2026) similarly examine five South Asian economies and identify renewable energy consumption as an important component of regional environmental sustainability. For Bangladesh, Qamruzzaman (2026) finds that renewable energy improves environmental sustainability, while trade openness and FDI exhibit more complex and asymmetric environmental effects. Together, these findings indicate that the environmental consequences of economic and trade expansion depend substantially on whether additional energy requirements are met by fossil or renewable sources. Because carbon intensity captures emissions relative to economic production, greater fossil fuel consumption can increase carbon intensity when the emissions generated by fossil-energy use rise faster than improvements in output efficiency. This relationship forms the second component of the proposed mediation mechanism.

H3: *Fossil fuel consumption has a positive and significant effect on carbon intensity in South Asian economies.*

2.4 Mediating Role of Fossil Fuel Consumption

Although trade-energy and trade–environment relationships have been extensively investigated, comparatively limited research integrates these relationships into a formal mediation framework. Existing studies generally treat energy consumption as an explanatory variable alongside trade openness rather than examining whether energy use represents a mechanism through which trade influences environmental outcomes. This distinction is important because identifying a significant trade coefficient alone does not reveal the economic pathway through which international integration changes environmental performance.

The theoretical mechanism proposed in this study is sequential. First, trade liberalization expands production, transportation, logistics, and industrial activity, potentially increasing fossil fuel consumption. Second, greater fossil fuel consumption increases the carbon burden associated with economic production. Trade liberalization may therefore affect carbon intensity both directly, through structural change, technology, investment, and specialization, and indirectly, through increased fossil-energy consumption. This mechanism is consistent with evidence linking trade with energy demand (Cole, 2006; Rahman, 2024) and trade with carbon intensity (Wang & Wang, 2021).

Recent evidence makes this mechanism increasingly relevant. Islam (2026) finds that both trade and energy consumption contribute to emissions in SAARC economies. Huang et al. (2025) report that trade openness worsens environmental pollution in Pakistan but that renewable energy mitigates this environmental pressure, suggesting that the energy structure can alter the environmental consequences of trade integration. Qamruzzaman (2026) similarly identifies interconnected and asymmetric relationships among trade openness, FDI, renewable energy, and environmental sustainability in Bangladesh. However, these recent studies do not directly test the specific mediation pathway proposed here: trade liberalization increases fossil fuel consumption, which subsequently leads to higher carbon intensity.

Accordingly, this study extends the existing literature by explicitly treating fossil fuel consumption as a mediator. A significant indirect effect would demonstrate that part of the environmental effect associated with trade liberalization operates through changes in fossil-energy dependence rather than exclusively through direct structural or technological channels. Based on this reasoning, the final hypothesis is:

H4: *Fossil fuel consumption significantly mediates the relationship between trade liberalization and carbon intensity in South Asian economies.*

Taken together, the four hypotheses establish an integrated trade–energy–environment mechanism. Trade liberalization is expected to increase fossil fuel consumption and carbon intensity, while fossil fuel consumption is expected to increase carbon intensity and transmit part of the environmental effect of trade liberalization. This framework extends the thesis's central argument that fossil fuel consumption should be examined as an intermediate transmission mechanism rather than merely another environmental determinant. The inclusion of recent 2025–2026 evidence also shows that the trade–energy–environment nexus remains highly relevant in contemporary South Asian research, while the specific mediation mechanism examined here remains a distinct contribution.

2.5 Literature Gap

Despite growing research on trade liberalization, energy consumption, and environmental sustainability, important gaps remain in the literature. Most existing studies focus on the direct effect of trade openness on aggregate or per-capita CO_2 emissions, while relatively limited attention has been given to carbon intensity as a measure of the carbon efficiency of economic production (Shahbaz et al., 2017; Wang & Wang, 2021; Hassan et al., 2025). Moreover, the trade–energy and energy–environment relationships are generally investigated separately. Previous studies show that trade liberalization influences energy and fossil fuel consumption (Cole, 2006; Ghani, 2012; Rahman, 2024), while energy use significantly affects environmental outcomes (Hassan et al., 2025; Islam, 2026; Begum et al., 2026). However, fossil fuel consumption is usually treated as an independent explanatory variable rather than as a transmission mechanism. Therefore, limited evidence exists on whether trade liberalization increases fossil fuel consumption, which subsequently affects carbon intensity. In addition, few studies provide an integrated analysis for South Asian economies while simultaneously considering cross-sectional dependence, heterogeneity, endogeneity, and distributional differences. This study addresses these gaps by examining seven South Asian economies over 1990–2023 and explicitly testing fossil fuel consumption as a mediator between trade liberalization and carbon intensity. By combining second-generation panel estimation with robustness, endogeneity, heterogeneity, and mediation analyses, the study provides a more comprehensive understanding of the energy channel through which trade liberalization influences environmental performance.

DATA AND METHODOLOGY

3.1 Research Design, Data Sources, and Variable Measurement

This study employs a quantitative panel-data framework to examine the relationships among trade liberalization, fossil fuel consumption, and carbon intensity in seven South Asian economies over 1990-2023. The balanced panel contains 238 country-year observations, with 34 annual observations for each country. The panel structure is appropriate because it combines cross-country and time-series variation and allows the analysis to account for common regional shocks and heterogeneous responses to trade integration, economic development, structural transformation, and changes in energy use.

Table 1. Variable Description and Data Sources

Variable	Symbol	Measurement	Source
Trade liberalization	LnTL	(Exports + Imports)/GDP × 100	World Bank, WDI
Fossil fuel consumption	LnFFC	Fossil fuel energy consumption (% of total)	IEA

Carbon intensity	LnCI	CO_2 emissions (kg) per constant US$ of GDP	World Bank, WDI
GDP per capita	LnGDP	GDP per capita, constant US$	World Bank, WDI
GDP squared	$LnGDP^2$	Squared logarithm of GDP per capita	Derived from WDI
Foreign direct investment	FDI	Net inflows (% of GDP)	World Bank, WDI
Industrialization	LnIND	Industry value added (% of GDP)	World Bank, WDI
Urbanization	LnURB	Urban population (% of total)	World Bank, WDI
Renewable energy	LnREN	Renewable energy consumption (% of total final energy consumption)	IEA

Table 1 presents the definitions, measurements, and data sources of all variables employed in the study. The data are obtained from internationally recognized sources. Most macroeconomic and structural indicators are collected from the World Bank's World Development Indicators (WDI), while fossil fuel consumption is obtained from the International Energy Agency (IEA), and renewable energy consumption is drawn from World Bank/IEA sources. Trade liberalization is the principal explanatory variable, fossil fuel consumption serves as both an outcome and mediating variable, and carbon intensity represents the final environmental outcome. GDP per capita, GDP squared, FDI, industrialization, urbanization, and renewable energy consumption are included as control variables. Natural logarithms are applied to all variables except FDI to reduce scale differences and facilitate elasticity-based interpretation. FDI is retained in percentage form because it contains negative observations.

3.2 Model Specification

The empirical framework is constructed to identify both the direct effects of trade liberalization and the indirect effect transmitted through fossil fuel consumption. Based on the theoretical framework, the three functional relationships are specified as:

$$FFC_{it} = f\,(TL_{it},\ GDP_{it},\ GDP^2_{it},\ FDI_{it},\ IND_{it},\ URB_{it},\ REN_{it})$$

$$CI_{it} = f\,(TL_{it},\ GDP_{it},\ GDP^2_{it},\ FDI_{it},\ IND_{it},\ URB_{it},\ REN_{it})$$

$$CI_{it} = f\,(TL_{it},\ FFC_{it},\ GDP_{it},\ GDP^2_{it},\ FDI_{it},\ IND_{it},\ URB_{it},\ REN_{it})$$

where FFC represents fossil fuel consumption, CI denotes carbon intensity, TL represents trade liberalization, GDP is GDP per capita, GDP^2 captures the nonlinear effect of economic development, FDI represents foreign direct investment, IND denotes industrialization, URB represents urbanization, and REN denotes renewable energy consumption.

The first model examines whether trade liberalization affects fossil fuel consumption. The second estimates the total effect of trade liberalization on carbon intensity, while the third incorporates fossil fuel consumption to determine whether the trade–carbon intensity relationship operates partly through changes in conventional energy use. For empirical estimation, Eqs. (1) - (3) are transformed as follows:

$$LnFFC_{it} = \propto_0 + \alpha_1 LnTL_{it} + \alpha_2 LnGDP_{it} + \alpha_3 LnGDP^2_{it} + \alpha_4 LnFDI_{it} + \alpha_5 LnIND_{it} + \alpha_6 LnURB_{it} + \alpha_7 LnREN_{it} + \mu_{it}$$

$$LnCI_{it} = \propto_0 + \alpha_1 LnTL_{it} + \alpha_2 LnGDP_{it} + \alpha_3 LnGDP^2_{it} + \alpha_4 LnFDI_{it} + \alpha_5 LnIND_{it} + \alpha_6 LnURB_{it} + \alpha_7 LnREN_{it} + \mu_{it}$$

$$LnCI_{it} = \propto_0 + \alpha_1 LnTL_{it} + \alpha_2 LnFFC_{it} + \alpha_3 LnGDP_{it} + \alpha_4 LnGDP^2_{it} + \alpha_5 LnFDI_{it} + \alpha_6 LnIND_{it} + \alpha_7 LnURB_{it} + \alpha_8 LnREN_{it} + \mu_{it}$$

Here, *i* denotes country, *t* denotes year, and μ_{it} is the error term. The principal coefficients capture the effects of trade liberalization on fossil fuel consumption and carbon intensity and the effect of fossil fuel consumption

on carbon intensity. Comparing the trade liberalization effect before and after including fossil fuel consumption provides the basis for the subsequent mediation analysis.

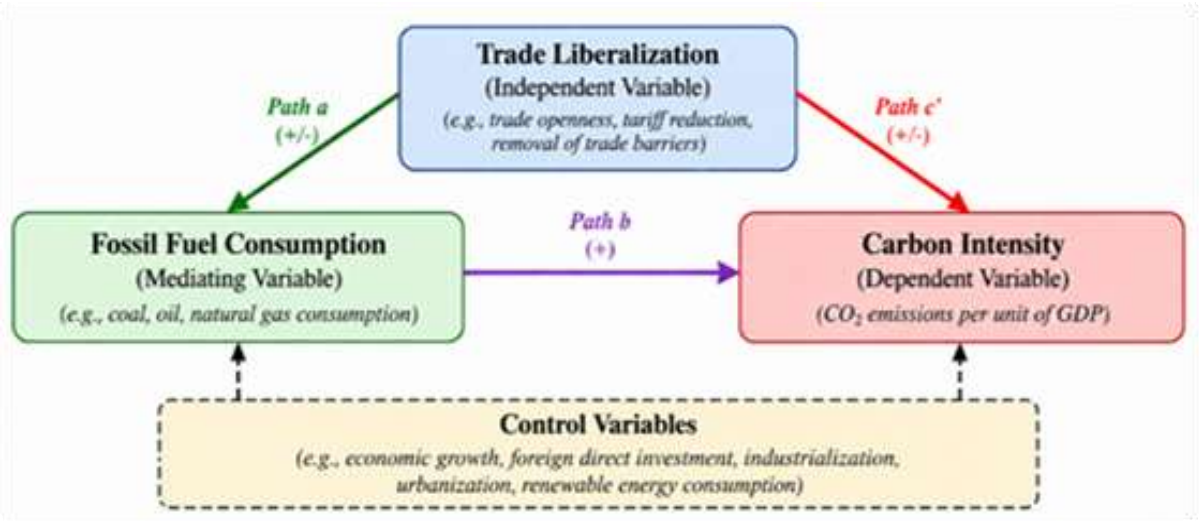


Figure 4: Conceptual Framework of the Study

Figure 4 presents the conceptual framework linking trade liberalization, fossil fuel consumption, and carbon intensity. Trade liberalization is the independent variable, fossil fuel consumption acts as the mediating variable, and carbon intensity is the dependent variable. The framework captures both the direct effect of trade liberalization on carbon intensity and its indirect effect through fossil fuel consumption, while economic growth, FDI, industrialization, urbanization, and renewable energy consumption are included as control variables.

3.3 Econometric Methodology

The empirical analysis follows a sequential econometric procedure to account for cross-sectional dependence, non-stationarity, cointegration, endogeneity, and heterogeneity. First, cross-sectional dependence is examined using the Breusch-Pagan LM test (Breusch & Pagan, 1980) and the Pesaran CD test (Pesaran, 2004), as South Asian economies may be simultaneously exposed to common trade, energy-price, financial, and macroeconomic shocks. The corresponding statistics are expressed as:

$$LM = T\sum_{i=1}^{N-1}\sum_{j=i+1}^{N}\hat{\rho}^2_{ij}$$

$$CD = \sqrt{\frac{2T}{N(N-1)}}\sum_{i=1}^{N-1}\sum_{j=i+1}^{N}\hat{\rho}_{ij}$$

where N represents the number of countries, T denotes the time dimension, and $\hat{\rho}_{ij}$ represents pairwise residual correlation.

Given the presence of cross-sectional dependence, the stationarity properties of the variables are examined using the second-generation Cross-Sectionally Augmented Dickey–Fuller (CADF) and Cross-Sectionally Augmented IPS (CIPS) tests developed by Pesaran (2007). These tests incorporate cross-sectional averages to account for common factors across countries. The CIPS statistic is expressed as:

$$CIPS = \frac{1}{N}\sum_{i=1}^{N} CADF_i$$

After establishing the order of integration, long-run relationships are examined using the Pedroni panel cointegration test (Pedroni, 1999, 2004) and the Westerlund error-correction-based cointegration test (Westerlund, 2007). The combined application of these tests provides complementary evidence regarding the existence of stable long-run relationships among trade liberalization, fossil fuel consumption, carbon intensity, and the control variables.

The Cross-Sectionally Augmented Autoregressive Distributed Lag (CS-ARDL) model is employed as the principal estimator. The approach is grounded in the Common Correlated Effects (CCE) framework of Pesaran (2006) and the dynamic heterogeneous-panel extension developed by Chudik and Pesaran (2015). CS-ARDL is particularly appropriate because it accommodates cross-sectional dependence, heterogeneous country responses, dynamic adjustment, and variables integrated at I(0) and I(1), provided none is I(2). Cross-sectional averages are incorporated into the model to capture unobserved common factors and cross-country spillovers. The general CS-ARDL specification is:

$$Y_{it} = \alpha_i + \sum_{j=1}^{p} \phi_{ij} Y_{i,t-j} + \sum_{j=0}^{q} \acute{\beta}_{ij} X_{i,t-j} + \sum_{j=0}^{p} \gamma_{ij} \bar{Y}_{t-j} + \sum_{j=0}^{q} \acute{\delta}_{ij} \bar{X}_{t-j} + \varepsilon_{it}$$

where Y_{it} denotes fossil fuel consumption or carbon intensity, X_{it} represents the explanatory variables, and $\bar{Y}_t$ represents cross-sectional averages. The CS-ARDL model is also represented in error-correction form to distinguish long-run effects from short-run adjustments. A negative and statistically significant error-correction coefficient indicates convergence toward long-run equilibrium following a short-run disturbance.

To examine the robustness of the CS-ARDL estimates, the analysis additionally employs (Kao & Chiang, 2000), Common Correlated Effects Mean Group (CCEMG) (Pesaran, 2006), and the Augmented Mean Group (AMG) estimator (Eberhardt & Teal, 2010). Additional sensitivity analyses use alternative variable proxies and exclude the 2020-2021 COVID-19 period. Potential endogeneity is further examined using System GMM (Blundell & Bond, 1998) and IV/2SLS, accompanied by the relevant serial-correlation, instrument-validity, identification, and weak-instrument diagnostics. Quantile regression and income-group estimations are also employed to investigate whether the estimated relationships vary across different levels of fossil fuel consumption, carbon intensity, and economic development.

Finally, mediation analysis evaluates whether fossil fuel consumption transmits part of the effect of trade liberalization to carbon intensity, following the mediation framework of Baron and Kenny (1986). Path a represents the effect of trade liberalization on fossil fuel consumption, path b captures the effect of fossil fuel consumption on carbon intensity conditional on trade liberalization, path c represents the total effect of trade liberalization on carbon intensity, and path c' represents the remaining direct effect after including fossil fuel consumption. The indirect effect is calculated as:

$$Indirect\ Effect = a \times b$$

Thus, the hypothesized transmission mechanism is trade liberalization → fossil fuel consumption → carbon intensity. The statistical significance of the indirect effect is assessed using the Sobel test (Sobel, 1982) and bootstrap confidence intervals (Preacher & Hayes, 2004; Hayes & Scharkow, 2013). Bootstrapping provides a more robust assessment of the indirect effect because it does not rely heavily on the assumption that the product of coefficients $a \times b$ follows a normal sampling distribution. A significant indirect effect provides evidence of mediation, while a significant remaining direct effect (c') is consistent with partial mediation.

EMPIRICAL RESULTS AND DISCUSSION

This section presents and discusses the empirical findings on the relationships among trade liberalization, fossil fuel consumption, and carbon intensity in South Asian economies. The analysis begins with preliminary diagnostic tests, followed by cointegration and CS-ARDL estimation of the short- and long-run relationships. Robustness, endogeneity, and heterogeneity analyses are then conducted to assess the consistency of the

findings. Finally, mediation analysis examines whether fossil fuel consumption serves as a transmission channel through which trade liberalization affects carbon intensity.

4.1 Descriptive Statistics and Correlation Analysis

Descriptive statistics provide an overview of the distribution and variation of the variables used in the analysis. Pairwise correlations indicate the direction and strength of associations among the variables and provide preliminary insights into their relationships. The analysis also helps identify potential multicollinearity concerns before proceeding to the main econometric estimations.

Table 2: Descriptive Statistics and Correlation Analysis

Variables	Obs.	Mean	Std. Dev.	Min	Max
LnTL	238	4.038	0.512	2.876	5.214
LnFFC	238	3.926	0.684	2.104	4.781
LnCI	238	0.421	0.684	-0.892	1.763
LnGDP	238	7.624	1.081	5.214	9.842
FDI	238	1.842	2.967	-8.421	17.624
LnIND	238	3.281	0.318	2.421	3.847
LnURB	238	3.421	0.514	2.214	4.381
LnREN	238	3.012	0.746	1.214	4.421
Note: ***, **, and * indicates significance at 1, 5, and 10 percent level respectively. Source: Author's Calculation					

As reported in Table 2, the descriptive statistics comprise 238 observations for each variable, confirming a balanced panel. Trade liberalization has a mean of 4.038, while fossil fuel consumption records a mean of 3.926, with both variables showing meaningful variation across countries and over time. Carbon intensity ranges from −0.892 to 1.763, indicating substantial differences in environmental performance across the sample. GDP per capita exhibits considerable variation, reflecting differences in economic development among South Asian economies. FDI shows the greatest dispersion, ranging from −8.421 to 17.624 percent of GDP, with negative values reflecting periods of net disinvestment. Industrialization and urbanization display relatively lower variation, whereas renewable energy consumption varies noticeably across countries and years.

Table 3. Pairwise Correlations and Multicollinearity Test

Variables	**(1)**	**(2)**	**(3)**	**(4)**	**(5)**	**(6)**	**(7)**	**(8)**	**VIF**	**Tolerance Value**
(1) LnTL	1.000								2.14	0.467
(2) LnFFC	0.412	1.000							2.31	0.433
(3) LnCI	0.365	0.528	1.000						2.48	0.403
(4) LnGDP	0.481	0.356	0.614	1.000					8.72	0.115
(5) FDI	0.286	0.214	0.251	0.318	1.000				1.38	0.725
(6) LnIND	0.321	0.528	0.472	0.417	0.186	1.000			2.16	0.463
(7) LnURB	0.287	0.421	0.384	0.512	0.165	0.393	1.000		2.43	0.412
(8) LnREN	−0.112	−0.274	−0.318	−0.184	−0.093	−0.214	−0.325	1.000	1.72	0.581
Source: Author's Calculation										

As reported in Table 3, trade liberalization is positively correlated with fossil fuel consumption (0.412) and carbon intensity (0.365), while fossil fuel consumption is positively associated with carbon intensity (0.528). These preliminary relationships are consistent with the proposed transmission mechanism from trade liberalization through fossil fuel consumption to carbon intensity, although correlations should not be interpreted as causal effects. GDP and industrialization also show relatively strong positive correlations with carbon intensity, whereas renewable energy consumption is negatively correlated with fossil fuel consumption (−0.274) and carbon intensity (−0.318). The correlation coefficients generally remain at moderate levels,

suggesting no serious pairwise multicollinearity. This is further supported by the VIF results, with values ranging from 1.38 to 8.72 and a mean VIF of 3.56. Although GDP records the highest VIF (8.72), it remains below the conventional threshold of 10.

4.2 Cross-Sectional Dependence

Cross-sectional dependence is examined to identify whether common economic, trade, and energy shocks affect countries within the panel simultaneously. Its presence is important for selecting appropriate second-generation panel estimation techniques.

Table 4. Cross-sectional dependence tests

Variable	Breusch-Pagan LM	Pesaran Scaled LM	Pesaran CD
LnFFC	64.382***	8.214***	6.731***
LnCI	62.184***	7.936***	6.482***
LnTL	48.763***	5.721***	5.104***
LnGDP	71.529***	9.214***	7.683***
$LnGDP^2$	69.841***	8.967***	7.421***
FDI	39.276***	4.318***	4.087***
LnIND	55.614***	6.842***	5.973***
LnURB	51.327***	6.091***	5.462***
LnREN	44.918***	5.026***	4.731***
Note: ***, **, and * denote significance at the 1%, 5%, and 10% levels, respectively. Source: Author's Calculation			

As reported in Table 4, the Breusch-Pagan LM, Pesaran Scaled LM, and Pesaran CD tests consistently reject the null hypothesis of cross-sectional independence at the 1% significance level for all variables. The results confirm substantial interdependence across the sampled economies, with particularly strong dependence observed for GDP and its squared term. Trade liberalization, fossil fuel consumption, and carbon intensity also exhibit significant cross-sectional dependence, indicating exposure to common regional and global shocks. Similar dependence is observed for FDI, industrialization, urbanization, and renewable energy consumption. These findings justify the use of second-generation panel techniques, including CIPS and CADF unit-root tests and cross-sectionally robust estimators.

4.3 Panel Unit Root Tests

Panel unit root tests are conducted to determine the stationarity and order of integration of the variables. Given the presence of cross-sectional dependence, the second-generation CIPS and CADF tests are employed. These tests establish whether the variables are stationary at level or first difference before proceeding to cointegration and CS-ARDL estimation.

Table 5: Panel Unit Root Tests

Variable	CIPS		CADF		Integration Order
	Level	1st Difference	Level	1st Difference	
LnTL	-2.184	-4.126***	-2.241	-4.318*	I(1)
LnFFC	-2.315	-4.482***	-2.387	-4.621*	I(1)
LnCI	-2.428	-4.215***	-2.514	-4.386*	I(1)
LnGDP	-2.106	-4.637***	-2.218	-4.814*	I(1)
FDI	-3.214***	-	-3.426***	-	I(0)
LnIND	-2.371	-4.328***	-2.486	-4.517*	I(1)
LnURB	-2.284	-4.416***	-2.391	-4.583***	I(1)
LnREN	-3.087**	-	-3.214**	-	I(0)
Note: ***, **, and * denote significance at the 1%, 5%, and 10% levels, respectively. Source: Author's Calculation					

As reported in Table 5, the CIPS and CADF unit root tests reveal a mixed order of integration among the study variables. LnTL, LnFFC, LnCI, LnGDP, LnIND, and LnURB are non-stationary at level but become stationary after first differencing, confirming that they are I(1). In contrast, FDI and LnREN are stationary at level and are therefore classified as I(0). The results are consistent across both second-generation unit root tests. Importantly, none of the variables is integrated of order two, I(2). Thus, the combination of I(0) and I(1) variables satisfies the integration requirements for applying the CS-ARDL approach. These findings provide the basis for proceeding to panel cointegration analysis and subsequent estimation of the short- and long-run relationships.

4.4 Panel Cointegration Results

Panel cointegration tests are conducted to determine whether the study variables maintain a stable long-run relationship. The Pedroni and Westerlund cointegration tests are employed to provide complementary evidence of long-run equilibrium relationships. Establishing cointegration provides the basis for estimating the long-run dynamics using the CS-ARDL approach.

Table 6. Panel Cointegration Test

Test	**Model 1**		**Model 2**	
	Statistics	**p-value**	**Statistics**	**p-value**
Pedroni Test				
Modified Phillips-Perron t	-4.2145***	0.000	-4.2187***	0.000
Phillips-Perron t	-38.6247***	0.000	-48.6735***	0.000
Augmented Dickey-Fuller t	-31.4826***	0.000	-38.4216***	0.000
Westerlund Test				
Variance Ratio	-3.4268***	0.000	-3.6142***	0.000
Note: ***, **, and * denote significance at the 1%, 5%, and 10% levels, respectively. Source: Author's Calculation				

As reported in Table 6, both the Pedroni and Westerlund tests provide strong evidence of cointegration for Models 1 and 2. In Model 1, the Modified Phillips-Perron, Phillips-Perron, and Augmented Dickey-Fuller statistics are -4.2145, -38.6247, and -31.4826, respectively, while the Westerlund variance ratio is -3.4268. Similarly, all statistics for Model 2 are statistically significant at the 1% level. The corresponding p-values of 0.000 reject the null hypothesis of no cointegration in both models. These findings confirm stable long-run relationships among the variables in the fossil fuel consumption and carbon intensity models, providing further justification for estimating their long-run and short-run dynamics using the CS-ARDL approach.

4.5 CS-ARDL Estimation Results

The CS-ARDL approach is employed to estimate the short- and long-run effects of trade liberalization and other explanatory variables on fossil fuel consumption and carbon intensity. The results are presented separately for Model 1 (fossil fuel consumption) and Model 2 (carbon intensity), while the error-correction term captures the speed of adjustment toward long-run equilibrium.

Table 7. CS-ARDL Estimation Results

Variables	**Model 1: LnFFC**		**Model 2: LnCI**	
	Long Run	**Short Run**	**Long Run**	**Short Run**
LnTL	0.326***	0.084***	0.284***	0.071***
	(0.074)	(0.021)	(0.067)	(0.022)
LnGDP	0.581***	0.214**	0.493***	0.086
	(0.142)	(0.098)	(0.128)	(0.091)
$LnGDP^2$	-0.062**	-0.018	-0.055**	-0.007
	(0.027)	(0.012)	(0.024)	(0.009)
FDI	0.084**	0.026	0.073**	0.008

	(0.039)	(0.019)	(0.034)	(0.013)
LnIND	0.291***	0.162**	0.267***	0.051
	(0.082)	(0.071)	(0.074)	(0.044)
LnURB	0.115**	0.041	0.103**	0.018
	(0.051)	(0.032)	(0.046)	(0.017)
LnREN	-0.184***	-0.072**	-0.169***	-0.019
	(0.053)	(0.034)	(0.049)	(0.020)
ECM(-1)	—	-0.421***	—	-0.398**
		(0.086)		(0.081)
R^2	0.782	0.694	0.742	0.681
Observations	238	238	238	238
Number of IDs	7	7	7	7
Note: ***, **, and * denote significance at the 1%, 5%, and 10% levels, respectively. Source: Author's Calculation				

As reported in Table 7, the CS-ARDL results show that trade liberalization significantly increases both fossil fuel consumption and carbon intensity in the long run. A 1% increase in trade liberalization is associated with a 0.326% increase in fossil fuel consumption and a 0.284% increase in carbon intensity, supporting the proposed positive relationships. Economic growth also has a positive long-run effect in both models, while the negative coefficients of GDP^2 indicate a nonlinear relationship in which the environmental and fossil-fuel effects of growth moderate at higher income levels. FDI, industrialization, and urbanization exert positive and statistically significant long-run effects on both fossil fuel consumption and carbon intensity. In contrast, renewable energy consumption has significant negative effects, reducing fossil fuel consumption by 0.184% and carbon intensity by 0.169% for a 1% increase in renewable energy use. In the short run, the error-correction terms are negative and statistically significant in both models, confirming convergence toward long-run equilibrium after short-run disturbances. The ECM coefficients of -0.421 for Model 1 and -0.398 for Model 2 imply that approximately 42.1% and 39.8% of disequilibrium, respectively, is corrected within one year.

4.6 Robustness Analysis

Robustness analysis is conducted to assess the consistency and reliability of the main CS-ARDL findings across alternative estimation techniques and model specifications. The analysis employs CCEMG and AMG. Consistent coefficient signs and significance across these specifications provide evidence of the robustness of the baseline results.

Table 8. Robustness Results: CCEMG and AMG

Variables	**Model 1: LnFFC**		**Model 2: LnCI**	
	CCEMG	**AMG**	**CCEMG**	**AMG**
LnTL	0.298***	0.314***	0.276***	0.291***
	(0.081)	(0.086)	(0.071)	(0.076)
LnGDP	0.542***	0.568***	0.481***	0.507***
	(0.157)	(0.164)	(0.134)	(0.141)
$LnGDP^2$	-0.058**	-0.061**	-0.052**	-0.058**
	(0.028)	(0.030)	(0.025)	(0.027)
FDI	0.079**	0.087**	0.070**	0.076**
	(0.038)	(0.041)	(0.036)	(0.039)
LnIND	0.276***	0.284***	0.259***	0.274***
	(0.089)	(0.094)	(0.079)	(0.083)
LnURB	0.108**	0.119**	0.098**	0.106**
	(0.052)	(0.055)	(0.047)	(0.051)
LnREN	-0.169***	-0.177***	-0.165***	-0.172***
	(0.057)	(0.060)	(0.052)	(0.055)

R^2	0.764	0.771	0.731	0.746
Observations	238	238	238	238
Number of IDs	7	7	7	7
Note: ***, **, and * denote significance at the 1%, 5%, and 10% levels, respectively. Source: Author's Calculation				

As reported in Table 8, the CCEMG and AMG estimates strongly support the robustness of the baseline CS-ARDL results. Trade liberalization remains positive and statistically significant at the 1% level across both estimators, with coefficients ranging from 0.298 to 0.314 for fossil fuel consumption and 0.276 to 0.291 for carbon intensity. Economic growth, FDI, industrialization, and urbanization also maintain positive and significant effects in both models, whereas GDP^2 remains negative, confirming the nonlinear growth relationship observed in the baseline estimates. Renewable energy consumption consistently exhibits a negative and significant effect on both fossil fuel consumption and carbon intensity. Overall, the similarity in coefficient signs, magnitudes, and significance across CCEMG and AMG confirms that the main findings are robust to alternative estimation techniques that account for cross-sectional dependence and heterogeneity.

4.7 Endogeneity Analysis

Endogeneity analysis is conducted to examine whether the estimated relationships are affected by potential simultaneity or omitted-variable bias. The analysis compares Pooled OLS estimates with Instrumental Variable (IV) regression, using legal origin as an instrument for trade liberalization. This approach provides an additional assessment of the robustness of the estimated effects of trade liberalization on fossil fuel consumption and carbon intensity.

Table 9. Pooled OLS and Panel IV Estimation Results

Variables/Diagnostics	**Model 1: LnFFC**		**Model 2: LnCI**	
	Pooled OLS	**Panel IV**	**Pooled OLS**	**Panel IV**
LnTL	0.326***	0.381***	0.284***	0.331***
	(0.074)	(0.118)	(0.067)	(0.091)
Control variables	Yes	Yes	Yes	Yes
Observations	238	238	238	238
R^2	0.782	0.746	0.742	0.716
Number of IDs	7	7	7	7
Wald χ^2 statistic	-	31.47	-	31.84
CD F-statistic	-	42.63	-	38.27
Kleibergen–Paap rk LM test	-	18.74	-	21.64
p-value	-	0.000	-	0.000
Cragg–Donald Wald F-statistic	-	27.86	-	18.72
Instrument	-	Legal Origin	-	Legal Origin
Note: ***, **, and * indicate significance at the 1%, 5%, and 10% levels, respectively. The Cragg-Donald Wald F-statistic values exceeding the conventional threshold of 10 indicate the absence of weak instrument problems. The Kleibergen-Paap rk LM test examines whether the model is under-identified. A statistically significant test statistic indicates that the model is identified. Source: Author's Calculation				

As reported in Table 9, the Pooled OLS and Panel IV estimates consistently show a positive and statistically significant effect of trade liberalization on both fossil fuel consumption and carbon intensity. For Model 1, the coefficient of trade liberalization increases from 0.326 under Pooled OLS to 0.381 under Panel IV, while for Model 2 it increases from 0.284 to 0.331, with all coefficients significant at the 1% level. The IV diagnostic results support the relevance of legal origin as an instrument: The Kleibergen-Paap rk LM statistics are significant in both models, rejecting under-identification. Moreover, the Cragg-Donald Wald F-statistics of 27.86 and 18.72 exceed the conventional threshold of 10, providing evidence against weak-instrument

concerns. Overall, the IV estimates preserve the positive effect identified in the baseline analysis, indicating that the main findings remain robust after addressing potential endogeneity of trade liberalization.

4.8 Heterogeneity Analysis

Heterogeneity analysis is conducted using quantile regression to examine whether the effect of trade liberalization varies across different levels of fossil fuel consumption and carbon intensity. This approach captures distributional differences that may not be reflected in average estimates.

Table 10a: Quantile Regression Results for Model 1

Variables	Q10	Q25	Q50	Q75	Q90
LnTL	0.182** (0.082)	0.231*** (0.074)	0.304*** (0.069)	0.376*** (0.081)	0.441*** (0.096)
LnGDP	0.394** (0.171)	0.462*** (0.143)	0.537*** (0.128)	0.618*** (0.151)	0.681*** (0.179)
$LnGDP^2$	-0.038* (0.021)	-0.047** (0.020)	-0.056** (0.023)	-0.065** (0.027)	-0.073** (0.031)
FDI	0.052 (0.041)	0.061* (0.035)	0.073** (0.033)	0.089** (0.039)	0.101** (0.046)
LnIND	0.194** (0.091)	0.226*** (0.078)	0.271*** (0.071)	0.315*** (0.084)	0.348*** (0.097)
LnURB	0.067 (0.052)	0.079* (0.045)	0.098** (0.043)	0.116** (0.049)	0.129** (0.058)
LnREN	-0.108** (0.050)	-0.126** (0.048)	-0.154*** (0.045)	-0.181*** (0.052)	-0.203*** (0.061)
Pseudo R^2	0.412	0.438	0.467	0.481	0.496
Observations	238	238	238	238	238
Number of ID's	7	7	7	7	7
Note: ***, **, and * denote significance at the 1%, 5%, and 10% levels, respectively. Source: Author's Calculation					

As reported in Table 10a, the quantile regression results reveal a consistently positive and significant relationship between trade liberalization and fossil fuel consumption across the conditional distribution. The coefficient of LnTL rises from 0.182 at Q10 to 0.441 at Q90, indicating that the positive association is larger at higher conditional quantiles of fossil fuel consumption. Economic growth and industrialization also remain positive and significant across the quantiles, while the negative coefficients of GDP^2 indicate a nonlinear relationship. FDI and urbanization generally become more pronounced at the middle and upper quantiles. In contrast, renewable energy consumption has a negative and significant coefficient across all quantiles, with its magnitude increasing from -0.108 at Q10 to -0.203 at Q90. Overall, the results demonstrate meaningful distributional heterogeneity in the estimated relationships, particularly for trade liberalization and renewable energy consumption.

Table 10b. Panel Quantile Regression Results for Model 2

Variables	Q10	Q25	Q50	Q75	Q90
LnTL	0.183*** (0.061)	0.221*** (0.057)	0.268*** (0.054)	0.314*** (0.059)	0.361*** (0.067)
LnGDP	0.351*** (0.119)	0.402*** (0.112)	0.467*** (0.108)	0.521*** (0.116)	0.574*** (0.129)
$LnGDP^2$	-0.036** (0.018)	-0.043** (0.017)	-0.051*** (0.016)	-0.057*** (0.018)	-0.063*** (0.020)
FDI	0.048* (0.027)	0.058** (0.025)	0.071*** (0.024)	0.078*** (0.027)	0.084*** (0.030)

LnIND	0.176*** (0.063)	0.207*** (0.059)	0.251*** (0.057)	0.286*** (0.061)	0.319*** (0.068)
LnURB	0.061* (0.035)	0.075** (0.032)	0.094*** (0.031)	0.108*** (0.034)	0.121*** (0.038)
LnREN	-0.112*** (0.041)	-0.128*** (0.038)	-0.151*** (0.037)	-0.169*** (0.040)	-0.187*** (0.044)
Pseudo R^2	0.184	0.207	0.231	0.248	0.261
Observations	238	238	238	238	238
Number of ID's	7	7	7	7	7
Note: ***, **, and * denote significance at the 1%, 5%, and 10% levels, respectively. Source: Author's Calculation					

As reported in Table 10b, the quantile regression results show that trade liberalization has a positive and statistically significant association with carbon intensity across all quantiles. The coefficient of LnTL increases from 0.183 at Q10 to 0.361 at Q90, indicating a larger positive association at higher conditional quantiles of carbon intensity. Economic growth and industrialization also exhibit positive and significant coefficients throughout the distribution, whereas the negative coefficients of GDP^2 indicate a nonlinear relationship. FDI and urbanization remain positive, with their coefficient magnitudes generally increasing toward the upper quantiles. In contrast, renewable energy consumption has a negative and significant coefficient across all quantiles, increasing in magnitude from -0.112 at Q10 to -0.187 at Q90. Overall, the results indicate substantial distributional heterogeneity and suggest that the estimated relationships are more pronounced at higher conditional levels of carbon intensity.

4.9 Mediation Analysis

Mediation analysis examines whether fossil fuel consumption serves as a transmission channel between trade liberalization and carbon intensity. The analysis estimates the direct, indirect, and total effects and assesses the significance of the indirect pathway using the Sobel test and bootstrap confidence intervals. This provides evidence on whether trade liberalization affects carbon intensity partly through changes in fossil fuel consumption.

Table 11a. Mediation Regression Results: Paths a, b, c, and c′

Variables	Model (1)	Model (2)	Model (3)
	(LnFFC)	(LnCI)	(LnCI)
LnTL	0.326***	0.284***	0.214***
	-0.074	-0.067	-0.061
LnFFC	-	-	0.218***
			-0.067
LnGDP	0.581***	0.493***	0.421***
	-0.142	-0.128	-0.119
$LnGDP^2$	-0.062**	-0.055**	-0.047**
	-0.027	-0.024	-0.022
FDI	0.084**	0.073**	0.069**
	-0.039	-0.034	-0.033
LnIND	0.291***	0.267***	0.238***
	-0.082	-0.074	-0.071
LnURB	0.115**	0.103**	0.091**
	-0.051	-0.046	-0.044
LnREN	-0.184***	-0.169***	-0.154***
	-0.053	-0.049	-0.047

ECM(-1)	-0.421*	-0.398*	-0.387*
	-0.086	-0.081	-0.079
R-squared	0.724	0.742	0.756
Observations	238	238	238
Number of ID's	7	7	7
Note: ***, **, and * denote significance at the 1%, 5%, and 10% levels, respectively.			
Source: Author's Calculation			

As reported in Table 11a, the mediation results provide evidence that fossil fuel consumption acts as a transmission channel between trade liberalization and carbon intensity. In Model 1, trade liberalization has a positive and significant effect on fossil fuel consumption (path a = 0.326, $p < 0.01$). Model 2 shows that the total effect of trade liberalization on carbon intensity is also positive and significant (path c = 0.284, $p < 0.01$). When fossil fuel consumption is introduced in Model 3, it has a positive and significant effect on carbon intensity (path b = 0.218, $p < 0.01$), while the coefficient of trade liberalization declines from 0.284 to 0.214 but remains statistically significant (path c′). This pattern is consistent with partial mediation, indicating that trade liberalization affects carbon intensity both directly and indirectly through fossil fuel consumption. The formal significance of the indirect effect should be confirmed by the subsequent Sobel and bootstrap tests.

Table 11b: Sobel Test for Mediation Effect

Mediation Effect	Coefficient	Standard Error	Z-statistic	p-value
Path (a): (LnTL → LnFFC)	0.326***	0.074	4.405	0.000
Path (b): (LnFFC → LnCI)	0.218***	0.067	3.254	0.001
Total effect (c): (LnTL → LnCI)	0.284***	0.067	4.239	0.000
Direct effect (c'): (LnTL → LnCI)	0.214***	0.061	3.508	0.000
Indirect effect (a × b)	0.071*	0.027	2.617	0.009
Note: ***, **, and * denote significance at the 1%, 5%, and 10% levels, respectively. Source: Author's Calculation				

As reported in Table 11b, the Sobel test confirms the mediating role of fossil fuel consumption in the relationship between trade liberalization and carbon intensity. Trade liberalization significantly increases fossil fuel consumption (path a = 0.326, $p < 0.01$), while fossil fuel consumption significantly increases carbon intensity (path b = 0.218, p = 0.001). The resulting indirect effect (a×b) is 0.071, with a Sobel Z-statistic of 2.617 and a p-value of 0.009, confirming that the indirect effect is statistically significant. The direct effect of trade liberalization remains positive and significant after including fossil fuel consumption (c′ = 0.214, $p < 0.01$), compared with the total effect of 0.284. These findings provide evidence of partial mediation, indicating that trade liberalization affects carbon intensity both directly and indirectly through increased fossil fuel consumption.

Table 11c. Bootstrap Test of the Indirect Effect

Effect	Coefficient	Bootstrap SE	95% Confidence Interval	Decision
Total effect (c)	0.284***	0.067	[0.153, 0.415]	Significant
Direct effect (c')	0.214***	0.061	[0.095, 0.335]	Significant
Indirect effect (a × b)	0.071*	0.025	[0.024, 0.124]	Significant
Mediation proportion	24.9%	-	-	Partial mediation
Note: ***, **, and * denote significance at the 1%, 5%, and 10% levels, respectively. Source: Author's Calculation				

As reported in Table 11c, the bootstrap results provide further evidence of the mediating role of fossil fuel consumption. The total effect of trade liberalization on carbon intensity is positive and significant (0.284), while the direct effect remains significant at 0.214 after accounting for fossil fuel consumption. More importantly, the indirect effect is 0.071, with a 95% bootstrap confidence interval of [0.024, 0.124]. Since this

interval does not include zero, the indirect effect is statistically significant, confirming the mediation effect. The indirect pathway accounts for approximately 24.9% of the total effect, while the remaining effect operates directly. Overall, the bootstrap evidence supports partial mediation, confirming that fossil fuel consumption is an important channel through which trade liberalization influences carbon intensity.

4.10 Discussion of the Study

The empirical findings establish a coherent relationship among trade liberalization, fossil fuel consumption, and carbon intensity in South Asian economies. The CS-ARDL estimates show that trade liberalization significantly increases both fossil fuel consumption and carbon intensity in the long run. This finding is consistent with the scale and composition effects of trade, whereby greater international integration expands production, transportation, industrial activity, and energy demand, particularly when production systems remain dependent on conventional energy sources (Antweiler et al., 2001; Copeland & Taylor, 2004). Cole (2006) similarly finds that trade liberalization can increase national energy use through changes in economic scale and industrial composition, while Ghani (2012) demonstrates that the trade–energy relationship depends on countries' development conditions. More specifically, Rahman (2024) documents an important relationship between trade development and fossil fuel consumption across South Asian economies. Therefore, the present findings reinforce earlier evidence that the energy consequences of trade expansion depend substantially on the structure of the energy system supporting increased economic activity.

The results further indicate that economic growth, FDI, industrialization, and urbanization increase fossil fuel consumption and carbon intensity, whereas renewable energy consumption reduces both outcomes. The positive GDP coefficient combined with the negative GDP-squared coefficient indicates a nonlinear relationship, consistent with the broader argument that the environmental consequences of economic growth may change as economies develop (Grossman & Krueger, 1995; Stern, 2004). Industrialization and urbanization are particularly relevant because the expansion of manufacturing, infrastructure, transportation, and urban activity can increase energy requirements when fossil fuels remain prominent in the energy mix. This interpretation is consistent with Hassan et al. (2025), who report that industrialization, trade openness, and urbanization contribute to environmental pressure in South Asia, whereas renewable energy improves environmental quality. Similarly, Rahman and Velayutham (2020) demonstrate the importance of distinguishing renewable from non-renewable energy in understanding the energy–growth relationship in South Asian economies. The negative effect of renewable energy in the present study therefore indicates that a cleaner energy mix can reduce both fossil fuel dependence and the carbon intensity of economic activity.

The positive effect of trade liberalization on carbon intensity should nevertheless not be interpreted as a universal consequence of trade openness. Theoretical and empirical research shows that trade can generate competing scale, composition, and technique effects, meaning that its ultimate environmental impact depends on production structure, technology, regulation, investment, and energy composition (Antweiler et al., 2001; Copeland & Taylor, 2004). Shahbaz et al. (2017) also demonstrate that the trade openness–carbon emissions relationship varies across countries and different levels of trade integration. More directly, Wang and Wang (2021), using evidence from 104 countries and regions, find a heterogeneous and nonlinear relationship between trade openness and carbon intensity and identify an important conditioning role for FDI. In the present South Asian sample, the positive relationship suggests that the scale and composition effects associated with trade expansion currently outweigh potential efficiency and technological gains. This interpretation is strengthened by the CCEMG and AMG robustness estimates and the IV analysis, while the quantile results show that the magnitude of the positive trade coefficient increases toward the upper conditional quantiles of both fossil fuel consumption and carbon intensity.

Most importantly, the mediation analysis identifies fossil fuel consumption as a significant transmission channel between trade liberalization and carbon intensity. Trade liberalization increases fossil fuel consumption, which subsequently contributes to higher carbon intensity. This mechanism is consistent with Cole (2006), Ghani (2012), and Rahman (2024), who establish that trade integration can influence energy demand and fossil fuel consumption, and with Wang and Wang (2021), who demonstrate that trade openness can affect carbon intensity. The indirect effect is statistically significant according to both the Sobel and bootstrap tests, providing formal evidence for the proposed mediation pathway. At the same time, the direct

effect of trade liberalization on carbon intensity remains statistically significant after fossil fuel consumption is incorporated into the model. This pattern supports partial mediation, consistent with the interpretation of mediation in which a significant indirect pathway can coexist with a remaining direct relationship (Baron & Kenny, 1986; Preacher & Hayes, 2004; Hayes & Scharkow, 2013).

This mediation result represents the central contribution of the study. Previous research has largely examined different components of the trade–energy–environment relationship separately. Cole (2006) and Ghani (2012) focus on how trade liberalization influences energy consumption, while Rahman (2024) provides direct evidence on the relationship between trade development and fossil fuel consumption in South Asia. In a separate strand of the literature, Shahbaz et al. (2017) examine the trade openness–carbon emissions nexus, and Wang and Wang (2021) demonstrate that trade openness influences carbon intensity under heterogeneous economic conditions. Recent South Asian evidence also establishes interconnected relationships among trade openness, energy use, industrialization, urbanization, renewable energy, and environmental outcomes (Hassan et al., 2025; Islam, 2026). The present study connects these previously separated relationships within a single empirical framework by demonstrating that part of the relationship between trade liberalization and carbon intensity operates specifically through increased fossil fuel consumption. In this respect, treating fossil fuel consumption as a mediator rather than merely another explanatory variable provides a clearer explanation of the energy-based mechanism underlying the trade–environment relationship.

Overall, the findings suggest that the environmental consequences of trade integration depend critically on the energy composition of trade-led economic expansion. Trade liberalization itself need not inevitably generate higher carbon intensity because the scale effect associated with greater production can potentially be counterbalanced by technological improvements and cleaner production processes (Antweiler et al., 2001; Copeland & Taylor, 2004). However, where additional production, transportation, and industrial energy requirements continue to be supplied predominantly through fossil fuels, trade expansion can intensify environmental pressure. The negative effect of renewable energy found in this study is consistent with evidence that greater renewable energy consumption can support a more sustainable growth pathway in South Asian economies (Rahman & Velayutham, 2020; Hassan et al., 2025). Accordingly, expanding renewable energy, improving industrial energy efficiency, facilitating cleaner technologies, and encouraging environmentally sustainable foreign investment can weaken the fossil-fuel transmission channel. Such measures can help South Asian economies capture the economic opportunities associated with international trade while progressively reducing the carbon intensity of trade-led development.

CONCLUSION AND POLICY RECOMMENDATIONS

5.1 Conclusion

This study examines the relationships among trade liberalization, fossil fuel consumption, and carbon intensity in seven South Asian economies over the period 1990–2023, with particular attention to the mediating role of fossil fuel consumption. The findings demonstrate that trade liberalization significantly increases fossil fuel consumption, suggesting that greater trade integration expands production, transportation, industrial activity, and associated energy demand under the prevailing fossil-fuel-dependent energy structure. Economic growth, FDI, industrialization, and urbanization also contribute positively to fossil fuel consumption, whereas renewable energy consumption reduces dependence on conventional energy sources.

The results further show that trade liberalization significantly increases carbon intensity. Economic growth, FDI, industrialization, and urbanization also exert positive effects on carbon intensity, while renewable energy consumption has a significant mitigating effect. The positive coefficient of economic growth together with the negative coefficient of its squared term indicates a nonlinear relationship between economic development and environmental pressure. The robustness results from CCEMG and AMG support the main CS-ARDL findings, while the instrumental-variable analysis confirms that the principal trade liberalization relationships remain after accounting for potential endogeneity. Quantile regression further reveals that the coefficient of trade liberalization becomes larger toward the upper conditional quantiles of both fossil fuel consumption and carbon intensity, demonstrating important distributional heterogeneity.

Most importantly, the mediation analysis demonstrates that fossil fuel consumption is a significant transmission channel between trade liberalization and carbon intensity. Trade liberalization increases fossil fuel consumption, which subsequently contributes to higher carbon intensity. The Sobel and bootstrap results confirm the significance of this indirect pathway. Since the direct effect of trade liberalization remains significant after fossil fuel consumption is incorporated, the findings support partial mediation. Thus, trade liberalization affects carbon intensity both directly and indirectly through fossil fuel consumption. Overall, the study establishes a coherent trade–energy–environment mechanism and demonstrates that the environmental consequences of trade integration depend substantially on the energy structure supporting trade-led economic activity.

5.2 Policy Recommendations

The findings suggest that South Asian economies should coordinate trade liberalization with energy, industrial, investment, transport, and environmental policies. Trade expansion should be accompanied by greater investment in renewable energy so that additional production and transportation requirements do not translate directly into greater fossil fuel consumption. Governments should facilitate access to renewable-energy technologies, energy-efficient machinery, cleaner production equipment, and other low-carbon capital goods. Industrial and investment policies should also encourage energy-efficient production and cleaner FDI. Incentives for foreign and domestic investors can be linked with technological upgrading, renewable-energy adoption, and improvements in energy efficiency. Similarly, trade-related transportation and logistics systems should be modernized through efficient freight networks, improved port operations, digital trade facilitation, and cleaner transportation technologies. Urban development should prioritize efficient public transportation, energy-efficient buildings, and cleaner electricity systems. These measures would not require restricting trade integration; rather, they would help weaken the fossil-fuel channel through which trade expansion contributes to carbon intensity. The central policy objective should therefore be to decouple trade-led economic expansion from fossil fuel dependence while preserving the economic opportunities generated by international integration.

5.3 Limitations of the Study

Several limitations should be acknowledged. First, trade liberalization is measured using trade openness, which captures overall international integration but does not distinguish among tariff reductions, non-tariff measures, trade agreements, customs reforms, and other specific trade-policy changes. Second, fossil fuel consumption is measured at the aggregate level and therefore does not distinguish among coal, oil, and natural gas, which have different uses and environmental consequences. Third, carbon intensity is measured at the national level, preventing identification of the specific contribution of manufacturing, transportation, electricity generation, construction, or other sectors. Furthermore, the mediation analysis focuses specifically on fossil fuel consumption. The presence of partial mediation indicates that additional mechanisms may transmit the effect of trade liberalization to carbon intensity, including technological change, industrial composition, transportation activity, energy efficiency, and the composition of FDI. Finally, the study covers seven South Asian economies; therefore, differences in economic structures, energy systems, institutions, and trade patterns should be considered when extending the findings to other regions.

5.4 Future Research

Future studies can extend this research by employing more detailed indicators of trade liberalization, including tariff rates, non-tariff measures, trade agreements, customs reforms, and sector-specific liberalization measures. This would help distinguish actual policy liberalization from broader changes in trade openness. Future research could also disaggregate fossil fuel consumption into coal, oil, and natural gas and examine whether particular fuel sources play a stronger mediating role between trade liberalization and carbon intensity. Further research could use sector-level carbon intensity to identify whether the trade-energy-environment mechanism differs across manufacturing, agriculture, transportation, and other trade-exposed sectors. Because the present study identifies partial mediation, future studies could investigate additional mediators such as technological innovation, energy efficiency, industrial composition, renewable-energy transition, transportation activity, and the composition of foreign investment. Institutional quality and environmental reg-

ulation could also be examined as potential moderators of these transmission mechanisms. Finally, extending the analysis to other developing regions and using firm-level or industry-level data would help determine whether the identified trade liberalization–fossil fuel consumption–carbon intensity pathway is specific to South Asia or represents a broader feature of developing economies.

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