

Decoupling Carbon Emissions and Economic Growth: Evidence from South Asia

Kumar Gaurav

*Senior Assistant Professor, Department of Economics, S.N. Sinha College, Tekari (Magadh University, Bodh Gaya), Gaya 824236, Bihar, India
(Email: kumargauraviitp@gmail.com)*

ABSTRACT

One of the most crucial aspects for understanding sustainable development has been a correlation between economic growth and environmental impacts. Moreover, the environment and the economy are interlinked and decoupling is an important metric integrating the two. The present study evaluates decoupling of carbon emissions and economic growth in South Asian countries from 1990 to 2023. South Asia has been historically heavily dependent on coal and fossil fuels for their economic growth, making it energy-intensive and high-carbon region with the exception of Bhutan. This study applies the Stochastic Impacts by Regression on Population, Affluence, and Technology (STIRPAT) model framework. STIRPAT model is advancement over the conventional IPAT identity. The factors used in the study are carbon emissions, population, affluence, technology, urbanization, and trade openness to capture the impact of economic growth on emissions in South Asia. The STIRPAT model is estimated by both Common Correlated Effects Mean Group (CCEMG) and Augmented Mean Group (AMG) for ensuring robustness of the estimates. The data has been compiled from the World Bank's World Development Indicators (WDI), European Commission's Emissions Database for Global Atmospheric Research (EDGAR), and the Asian Development Bank (ADB). This study also tests the Environmental Kuznets Curve (EKC) by applying the inverted U-hypothesis test. Furthermore, the Pollution Haven Hypothesis (PHH) is also tested to determine whether South Asian countries serve as 'pollution havens'. South Asian countries require a swift transition to green economic growth framework which demands structural policy initiatives and stringent environmental regulations.

Keywords: Decoupling, Carbon Emissions, Sustainable Development, STIRPAT Model, Environmental Kuznets Curve (EKC), Pollution Haven Hypothesis (PHH)

INTRODUCTION

A country's development has historically been measured by economic growth – an increase in Gross Domestic Product (GDP) or National Income. Over time, economic

development was differentiated from economic growth and was defined as economic growth accompanied by improvements in well-being or quality of life. Later, the concept of sustainable development emerged in the late 1970s, to refer to improvements in well-being without material growth (Gallopín, 2003).

Normally, as economic growth occurs, energy consumption increases, which in turn causes an increase in carbon emissions (Wan, Wang & Ng, 2016). The link between environmental impact and economic growth has been one of the most intricate and crucial aspects of sustainable development (Wang et al., 2018). Since environment and economy are interlinked, decoupling is an important metric that integrates the two (Lin et al., 2015). Carbon emissions are mainly linked to industrial production in developing economies (Lv, Tang, & Ding, 2024). However, a low- emission economy with rapid economic growth is possible (Quaye et al., 2025; Haberl et al., 2020; Berahab, 2017). Changes in the energy landscape, such as a shift from non-renewable to renewable sources for production and consumption, improved energy efficiency, and reduced carbon intensity, can lead to decoupling.

In contrast to the common view that efficiency reduces consumption of resources and lowers environmental footprint, Jevons' paradox suggests that efficiency policies can be counterproductive (Alcott, 2005). The overburdening of the planet and its depleting natural resources are matters of concern. Efforts by individuals in reducing carbon emissions (CO_2) in an economy are limited by the free-rider problem: individual incentives remain questionable, and therefore, government accountability increases in this context (Cheng et al., 2022). The ideas of green growth (Tenaw & Hawitibo, 2021) and the circular economy rely on the concept of decoupling. The term has many connotations in economic literature. The OECD (2002, 2025) has defined decoupling as breaking the link between 'environmental bads' and 'economic goods.' Thus, decoupling refers to a condition where an economy grows while reducing carbon emissions, thereby reducing adverse environmental impact (Parrique et al., 2019; Quaye et al., 2025).

The majority of the literature on decoupling focuses on China, OECD countries, the European Union, the United States and other developed economies. Home to over 25% of world's population but accounting for barely over 4% of global GDP (nominal), South Asia contributes around 10% of global GHG emissions. South Asia has historically been heavily dependent on coal and fossil fuels for its economic growth, making it an energy-intensive and high-carbon region, with the exception of Bhutan which is a carbon-negative country. South Asian economies have seen weak evidence of decoupling, attributed to rapid urbanization, energy-intensive manufacturing and fossil-fuel consumption. In the pre-Covid period, the region recorded 8% of economic growth in 2016, which seized during the pandemic, but rebounded in the post-Covid period; nonetheless, South Asia's high economic growth has been achieved at the expense of environmental cost (Khoury, 2022).

This study applies the Stochastic Impacts by Regression on Population, Affluence, and Technology (STIRPAT) framework to examine the decoupling of carbon emissions and economic growth in South Asia from 1990-2023. Furthermore, it tests the Environmental Kuznets Curve (EKC) and the Pollution Haven Hypothesis (PHH) to determine whether South Asian countries serve as 'pollution havens'.

Studies on decoupling in South Asia are largely missing from the literature. This study attempts to fill that gap. It recommends structural policy initiatives, such as heavy investments in green energy sources, green finance, innovation in energy-efficient technologies, circular supply chains, reduction in fossil fuel subsidies, sustainable production and consumption, and stringent environmental regulations.

LITERATURE REVIEW

Human activities are the most significant contributors to greenhouse gas (GHG) emissions in the environment. With increasing population and rapid urbanization, economic growth and environmental footprint must be balanced (Gaurav, 2025). Technological progress and structural changes in the economy can lead to decoupling. The inverse relation between human progress and the environment has surfaced prominently since the late 1980s following the 'Brundtland Report' in 1987 (Sanyé-Mengual, 2019). Decoupling is not merely an eco-efficiency measure, but rather an indicator of improved sustainability. Parrique et al. (2019) identified that there is no empirical evidence in the literature that concludes that absolute decoupling has presently occurred. When it comes to the use of natural resources and economic growth, no absolute decoupling has happened.

Wan, Wang & Ng (2016) analyzed the decoupling between carbon emissions and economic growth for the equipment manufacturing industry in China during 2000-2014, applying LMDI decomposition and Tapio decoupling techniques, and observed weak decoupling between emissions and economic growth. Xu et al. (2024) explored the nexus between carbon emissions and energy consumption from 2000 to 2020 for one metropolitan area of China, Chengdu, by applying a coupled method, Tapio decoupling and LMDI decomposition techniques, along with an expanded STIRPAT method for forecasting the carbon emissions path. The major findings revealed that carbon emissions are concentrated in highly developed urban zones that lack forest cover for carbon sinks. Additionally, the decoupling between emissions and economic development is weak. However, energy intensity has been the key factor in reducing the carbon emissions. Wang et al. (2024) examined carbon emission and economic growth decoupling in China's six central provinces by using decoupling index (Tapio) based on the LMDI technique for 2000-2019 and an extended STIRPAT model for forecasting during 2000-2040. The major findings revealed a steady decoupling state during the study period for all six provinces. The decoupling status is guided by economic development and energy intensity. Cheng, Li

and Huangmei (2025) explored decoupling of economic growth and energy consumption in urban areas (prefecture cities) of China by using Tapio decoupling and a spatially weighted Durbin model developed from an augmented STIRPAT framework for the period from 2006 to 2021. The study found that decoupling is not uniform throughout the provinces of China; however, the number of weak decoupling regions decreased during the period from the 11th to the 14th Five-Year Plans. Various studies have been undertaken on economic growth and carbon emissions decoupling with a focus to China. However, other studies have also investigated the decoupling of economic growth and environmental degradation for various countries and regions, including OECD countries, the European Union, ECOWAS, Ukraine, the United States, and other developed countries.

Umpfenbach (2013) observed the decoupling of economic growth from resource use and environmental degradation, focusing on a policy framework for attaining absolute decoupling in the European Union, and applying the common approach based on examination of literature and conversations with stakeholders. The study proposed five major goals for 2050 for evaluating policy initiatives, including consumption of virgin metals, GHG emissions, arable land use, nutrients input, and freshwater use. Gupta (2015) studied decoupling between economic growth and environmental footprints in OECD countries. Based on the DPSIR technique delineated in the OECD report, the study concluded that relative decoupling had occurred for some selected indicators, demanding stringent policies for controlling fossil-fuel use, population, poverty, and corruption in the OECD countries. Haberl et al. (2020) investigated interlink among GDP, resource use, and greenhouse gas (GHG) emissions based on systematic literature survey from 1972 to 2019. The detailed study concluded that the direction of causality is inconclusive; however, GDP and energy are firmly associated. Although some industrialized countries have witnessed absolute decoupling, the findings cannot be generalized. Yareмова and Mytrofanova (2022) explored decoupling as a measure of economic growth and environmental footprints for territories of Ukraine during 2016-2020, applying common methods and approaches for analysis. Most regions of Ukraine are at a positive level of decoupling, with critical levels in four territories, while seven regions show an upward decoupling trend. Ayensu and Sun (2025) studied the decoupling of economic growth and carbon emissions with reference to fifteen ECOWAS members using the Tapio decoupling method during 1991 to 2020. The major findings include strong negative and recessive decoupling for the states of ECOWAS. Arino and Wang (2025) examined the decoupling of resource consumption and economic growth in China, Europe and the United States using the decoupling analysis method during 2000-2019. The US attained steady decoupling; European countries exhibited mixed decoupling, while China displayed weak decoupling. Quayе et al. (2025) examined economic growth and climate change decoupling in view of consumption-based emissions, using latent variable modeling framework for the period 2010-2018 for thirteen countries. Prospective consumption-based carbon emissions per capita are less responsive to changes in per capita GDP growth.

The literature on the decoupling of economic growth and emissions in South Asia is scarce. While studies on the impact of carbon emissions, population, trade openness, globalization, and other factors on economic growth and the environment are available, studies particularly on decoupling are missing. Decoupling theory has critical ramifications for comprehending the economic growth trajectories of the economies (Khosla et al., 2014). Countries like India and Germany can proceed towards community-based energy-ventures, advanced-grids, integrated urban transit, and social ventures for a circular economy and sustainable development. Rahman, Saidi, and Mbarek (2020) outlined the immediate and lasting implications of carbon emissions, population density, and trade openness on economic growth for five South Asian countries over the period 1990-2017. Carbon dioxide emissions and population density had a significant positive impact on South Asian economic growth; whereas trade openness and economic growth were negatively linked in the long term. Moreover, carbon emissions and economic growth displayed a two-way causal relationship in the short term. South Asia has not decoupled carbon emissions from economic growth. Department of Environment and Climate Change (2023) found substantially robust evidence of decoupling between green house gas (GHG) emission and GDP for Bhutan in the long term. The study projected that with a 25% of GDP increase, GHG emission would decrease by 20%. Although Bhutan is committed to carbon neutrality, GHG emissions are swiftly increasing attributable to economic development. Abbas, Yang, and Lahr (2024) analyzed the impact of globalization on carbon emissions in South Asia (India, Bangladesh, Sri Lanka, and Pakistan) during 1996-2019. Economic globalization significantly contributed to increased energy consumption and carbon emissions, and South Asia served as 'Pollution Haven' correlated to economic globalization only. Rani, Rehman, and Prisca (2025) discussed the effect of green energy and financial development on carbon emissions in South Asian countries using quantile regression for the period 2003-2023. Green energy effectively reduced carbon emissions, while financial development had a negative effect on carbon emissions. There is growing apprehension about the harmony between economic development and sustainability, regardless of high economic growth in South Asia, since these countries are experiencing degrading environment.

The reviewed literature reveals two contrasting sides of decoupling. One strand of a handful of literature confirms decoupling of economic growth and environmental sustainability, while other strand of literature concludes that for ecological sustainability, reducing production and consumption is essential. Additionally, majority of studies on decoupling focuses on China, OECD countries, the European Union and the United States; studies on South Asian decoupling is almost missing from the literature. This study attempts to fill that gap by exploring carbon emissions and economic growth decoupling in South Asia.

METHODOLOGY

Conceptual Framework of Decoupling

Decoupling has become a cornerstone of environmental policy and climate change mitigation strategies globally. In essence, decoupling refers to delinking economic growth (increase in GDP) from resource use and environmental footprint (Umpfenbach, 2013). It can be either relative (weak), where emissions reduce more slowly than economic growth (GDP), or absolute (strong), where emissions decline substantially despite economic growth. The simultaneous delinking of economic growth from both resource consumption and environmental footprint is termed as double decoupling (Khosla et al., 2014). Furthermore, UNEP (2011) has differentiated between resource decoupling and impact decoupling illustrated in Figure 1. Resource decoupling refers to the process of minimizing primary resource consumption rate for each unit of economic output. In contrast, impact decoupling is reducing environmental footprints (reducing carbon emissions), while rising economic production.

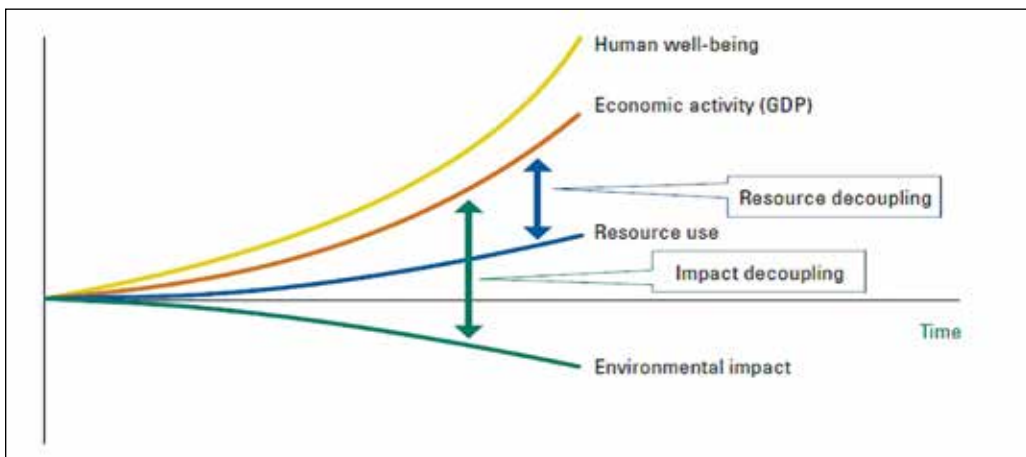


Fig. 1: Understanding the Resource and Impact Decoupling

Source: UNEP (2011)

Decoupling indicator (D) measures decoupling as a change in CO₂ emissions with respect to a change in GDP (Tapio, 2005; Berahab, 2017; Wang et al., 2024):

$$D = \frac{\Delta \text{CO}_2 \text{ Emissions}}{\Delta \text{GDP}}$$

Based on the measures of decoupling, it may be weak or strong. Weak decoupling happens when carbon emissions (CO₂) increases with an increase in GDP ($D > 0$). When with an increase in GDP, carbon emissions either fall or remain stable, it is termed as strong decoupling ($D < 0$).

STIRPAT Model Framework

This study has applied STIRPAT (Stochastic Impacts by Regression on Population, Affluence, and Technology) framework to capture the impact of carbon emissions on population, affluence and technology. The STIRPAT model is originated from IPAT identity (Commoner, 1971; Ehrlich & Holdren, 1972). The typical expression of the STIRPAT model is:

$$I = a P^{b_1} A^{b_2} T^{b_3} e$$

Here, I = Environmental Footprint, a = Constant, P = Population, A = Affluence, T = Technology, b_1 , b_2 , and b_3 = Elasticity Coefficients and e = Error term:

Converting the IPAT in the log-linear form

$$\ln(I) = \ln a + b_1 \ln(P) + b_2 \ln(A) + b_3 \ln(T) + \ln(e)$$

Adding the country (i) and time dimension (t), the expression can be written as

$$\ln(I_{it}) = \alpha + \beta_1 \ln(P_{it}) + \beta_2 \ln(A_{it}) + \beta_3 \ln(T_{it}) + \varepsilon_{it}$$

The dependent variable (I) used here is carbon dioxide (CO₂) emissions that measures environmental impact. Population (P) is the total population of South Asian countries (Urban population can also be used); Affluence (A) is measured by GDP per capita (PPP) indicating that with a rise in income, consumption level increases. Technology (T) corresponds to energy intensity, i.e., energy use per GDP which reflects how polluting the technology is. Augmenting the baseline model with urbanization (E₁), trade openness (E₂) the equation transforms to:

$$\ln(I_{it}) = \alpha + \beta_1 \ln(P_{it}) + \beta_2 \ln(A_{it}) + \beta_3 \ln(T_{it}) + \beta_4 \ln(E_{1it}) + \beta_5 \ln(E_{2it}) + \varepsilon_{it}$$

The STIRPAT model has been estimated using both the Common Correlated Effects Mean Group (CCEMG) and the Augmented Mean Group (AMG) to validate the robustness of the estimates. These are second-generation estimation techniques, which evaluate long-run relation in panel data. These statistical methods are used to address cross-sectional dependence and endogeneity problems.

Environmental Kuznets Curve (EKC)

This study also tests the Environmental Kuznets Curve (EKC) and the Pollution Haven Hypothesis (PHH) to examine whether the South Asian countries serve as 'pollution havens'. The Environmental Kuznets Curve (EKC) postulates that environmental degradation displays an increasing trend in the initial phases of economic development; however, it declines with increased levels of income and economic development (Khosla et al., 2014; Murthy & Gambhir, 2018). This indicates that there is an inverted U-shaped relationship between economic development and environmental damage. For a log-linear model, the turning-point (per capita GDP level), where theoretically emissions start declining:

$$\text{Turning Point} = e^{\frac{\beta_1}{2\beta_2}}$$

Here, β_1 = coeff. of $\ln_A$ (Affluence)

β_2 = coeff. of $\ln_A^2$ (sqr. of Affluence)

The rationale for this inverted U-shaped relationship is (the combined result of scale effect, composition effect, and technology effect) rooted in the argument that at higher levels of economic development, countries acquire the required pollution mitigation technologies and financial capital to impose stronger environmental regulations.

Pollution Haven Hypothesis (PHH)

The location of firms depends on a multitude of factors ranging from production costs to market access and government taxation policies; however, environmental regulation has emerged as a new determining factor for location overseas (Zugravu & Kheder, 2008). Countries having weak environmental regulatory policies attract foreign firms from countries where regulations are stringent. In this connection, the Pollution Haven Hypothesis (PHH) emerged during 1990s to explain the location of polluting firms (Bhat & Tantri, 2024). The PHH underscores that multinational corporations from developed countries, especially those involved in extremely polluting operations, reposition their firms to countries with weaker environmental regulations (Smarzynska & Wei, 2001; Temurshoev, 2006). Since developed countries usually have stricter environmental regulations compared to developing countries, motivates global firms to either relocate or offshore their polluting activities to countries with weaker environmental policies (Copeland & Taylor, 1994; Lee & Min, 2014; Shahbaz et al., 2015; Ozcelik et al., 2024).

Data Source and Sample

The empirical investigation is based on seven South Asian countries (Afghanistan was dropped due to data unavailability) covering the period from 1990 to 2023. To estimate the model, data on carbon dioxide emissions, population, GDP per capita, energy consumption, urbanization, and trade openness were compiled from the World Bank's World Development Indicators (WDI). Additionally, data on CO₂ emissions were supplemented with statistics from the European Commission's Emissions Database for Global Atmospheric Research (EDGAR), while trade openness data for the Maldives were extracted from the Asian Development Bank (ADB). The data sources, along with descriptions of the indicators, are presented in Table 1.

Table 1: Data Source

Variables	Indicator	Data Source
Impact (I)	Carbon Emissions measured by Total CO ₂ emissions (Mt CO ₂ e) excluding LULUCF	World Bank-WDI/EDGAR
Population (P)	Total Population	World Bank -WDI
Affluence (A)	Wealth/Income measured by GDP per capita (Constant 2015 or 2021 US\$)	World Bank- WDI
Technology (T)	Energy Efficiency measured by Energy intensity level of primary energy (MJ/\$2021 PPP GDP)	World Bank- WDI
Urbanization (E1)	Measured by urban population as % of total population	World Bank- WDI
Trade Openness (E2)	Trade as % of GDP	World Bank -WDI/ADB

Source: Author

EMPIRICAL RESULTS AND DISCUSSION

Descriptive statistics are presented in Appendix Table A, while summary of log-transformed variables is presented in Appendix Table B. Pairwise correlations among the variables are shown in Appendix Table C, which validates low multicollinearity among the variables, with the exception of $\ln_P$. To detect multicollinearity, the VIF was estimated and is shown in Appendix Table D. Since the mean VIF is 2.64 (thresholds are: $VIF < 5$ =No issue; $VIF < 10$ = tolerable), it is concluded that there is no serious multicollinearity issue. Prior to estimating the coefficients for the STIRPAT model, the Pesaran CD test for cross-sectional dependence was performed (see Appendix Table E). The results of the CD test confirmed significant cross-sectional dependence (mean rho of 96%). However, some countries exhibit negative correlation (mean rho= 0.45, abs =0.87); moreover, absolute dependence is high, indicating that South Asian countries are moving together. This is common for South Asian countries and is attributable to geographical proximity, common macroeconomic shocks, contiguous climate impacts, regional spillover effects, cultural and structural similarities, and regional free trade agreements (SAFTA). Given the high dependence, first-generation panel unit root tests (IPS, LLC) become unacceptable. Therefore, second-generation CIPS test and the CCEMG and the AMG estimators are applied to account for cross-sectional dependence. The results for the Westerlund ECM and the Pedroni and Kao tests are summarized in appendix Table F. The Pedroni and Kao tests validate strong long-run cointegration for the balanced panel (N=238) after dropping the technology variable ($\ln_T$).

Table 2 presents the main results from the CCEMG estimation for the STIRPAT model. For robustness, AMG estimates are also presented in the table. The estimated coefficient

for Population (P) is positive, but it is not significant under the CCEMG estimation. The elasticity for Affluence (A) is 1.125 ($p < 0.01$), showing that it is positive and significant. This indicates that a 1% increase in income (GDP per capita), increases carbon dioxide (CO_2) emissions by more than 1% for South Asian countries. Urbanization (E1) has a negative impact on carbon emissions; however, the coefficient is not significant. This finding implies that South Asian countries have not yet attained economies of scale effect, due to transition dynamics and low urbanization. Trade Openness (E2) coefficient is positive and significant (0.136, $p = 0.003$), indicating that with an increase in degree of openness, the environmental footprint increases. This is an interesting finding, as it validates the 'Pollution Haven Hypothesis (PHH)' in South Asia, along the lines of the findings of Abbas, Yang, and Lahr (2024). Technology (T) is dropped from the estimation due to 34% missing observations and its failure to pass the cointegration test for a long-run relationship. Estimation based on AMG, confirms the positive and significant effect of Affluence on the environment (carbon emissions) – an increase in per capita GDP increases carbon emissions. Moreover, trade openness is positive for both CCEMG and AMG; however, it is not significant under the AMG estimation.

Table 2: Results for STIRPAT Model

Variables	CCEMG Coefficients	Std. Error	p-value	AMG Coefficients	Std. Error	p-value
Population (P)	0.954	1.032	0.356	-0.422	0.518	0.417
Affluence (A)	1.125***	0.343	0.001	0.892***	0.218	0.000
Urbanization (E1)	-0.923	0.903	0.307	0.538	0.675	0.425
Trade Openness (E2)	0.136***	0.045	0.003	0.069	0.074	0.348
Constant	3.024	6.789	0.656	1.022***	0.364	0.005

Source: Author

- Notes:** 1. For CCEMG: Wald $\chi^2 = 20.17$ ($p = 0.0005$), RMSE=0.056; For AMG: Wald $\chi^2 = 100.85$ ($p = 0.0000$)
2. Model estimated without technology ($\ln_T$) since 34% data is missing and failed the co-integration test
3. Pedroni PP (Phillips-Perron) $p = 0.0037$, Kao $p = 0.0044$ without $\ln_T$, which confirmed long-run relation, CSD handled by using CCE

This study further tests the validity of the Environmental Kuznets Curve (EKC) hypothesis. The estimation based on the AMG supports the inverted-U proposition, since the coefficient of Affluence is positive ($\ln_A > 0$) and its square is negative ($\ln_A^2 < 0$), however, $\ln_A^2$ is not significant. The reason for this observation is that mostly the observations lie prior to the peak of the EKC. With a mean $\ln_A$ of 7.373552, the mean

per capita GDP is $\exp(7.373552)$ which amounts to \$1594. The turning point (peak) will be achieved at a per capita GDP of \$2495.5 [Turning point = $\exp\{\ln_A(\text{mean}) + 0.4487\} = \exp(7.373552 + 0.4487) = 2495.5$]. At present, the average per capita GDP of South Asia is \$1594, while the EKC turning point will be achieved at \$2495.5. These results validate that South Asia has not attained decoupling of carbon emissions from economic growth. This finding is consistent with Rahman, Saidi, and Mbarek (2020).

CONCLUSIONS AND SUGGESTIONS

The present study explores the decoupling of carbon emissions and economic growth in South Asia from 1990 to 2023, applying the STIRPAT framework. The STIRPAT model is estimated by using both CCEMG and AMG to validate robustness of the estimates. The study also tests the Environmental Kuznets Curve (EKC) and the Pollution Haven Hypothesis (PHH). The findings confirm that carbon emissions increase with an increase in per capita GDP in South Asia. Moreover, South Asia serves as a 'Pollution Haven', as the positive and significant coefficient of trade openness confirms the PHH. Furthermore, South Asian countries exhibit an inverted-U relationship (Environmental Kuznets Curve Hypothesis); however, these countries have not yet reached the turning point. These results validate that South Asia has not decoupled carbon emissions from economic growth. These countries require a swift transition to a green economic growth framework, which demands structural policy initiatives such as heavy investments in green energy sources, green finance, innovation in energy-efficient technology, circular supply chains, reduction in fossil fuel subsidies, sustainable production and consumption, and stringent regulations.

REFERENCES

- Abbas, M., Yang, L., & Lahr, M. L. (2024). Globalization's effects on South Asia's carbon emissions, 1996–2019: A multidimensional panel data perspective via FGLS. *Humanities & Social Sciences Communications*, 11(1). <https://doi.org/10.1057/s41599-024-03704-z>
- Alcott, B. (2005). Jevons' paradox. *Ecological Economics: The Journal of the International Society for Ecological Economics*, 54(1), 9–21. <https://doi.org/10.1016/j.ecolecon.2005.03.020>
- Ariño, M. A., & Wang, H. (2025). Decoupling resource consumption from economic growth: A comparative study of China, Europe, and the United States. *Journal of Sustainability*, 1(2). <https://doi.org/10.55845/jos-2025-1251>
- Ayensu, F., & Sun, D. (2025). Decoupling approach to carbon emissions and economic growth nexus: Evidence from ECOWAS member states. <https://doi.org/10.2139/ssrn.5110384>
- Berahab, R. (2017). *Decoupling economic growth from CO2 emissions in the world* (Policy Brief PB-17/27). OCP Policy Center.
- Bhat, V., & Tantri, M. L. (2024). Pollution haven hypothesis and the bilateral trade between India and China. *Journal of Current Chinese Affairs*, 53(2), 277–302. <https://doi.org/10.1177/18681026231188450>

- Cheng, H., Li, C., & Huangmei, M. (2025). An examination of the decoupling effect and influential mechanisms of energy consumption and economic growth in Chinese urban areas. *Scientific Reports*, 15(1), 31190. <https://doi.org/10.1038/s41598-025-16262-4>
- Cheng, S., Wang, P., Chen, B., & Fan, W. (2022). Decoupling and decomposition analysis of CO₂ emissions from government spending in China. *Energy*, 243, 122741. <https://doi.org/10.1016/j.energy.2021.122741>
- Commoner, B. (1971). *The closing circle: Nature man and technology*. Knopf.
- Copeland, B. R., & Taylor, M. S. (1994). North-South trade and the environment. *The Quarterly Journal of Economics*, 109(3), 755–787. <https://doi.org/10.2307/2118421>
- Department of Environment and Climate Change (2023). Bhutan's long-term low greenhouse gas emission and climate resilient development strategy (LTS). Ministry of Energy and Natural Resources, Royal Government of Bhutan.
- Ehrlich, P., & Holdren, J. (1972). A bulletin dialogue on the 'closing circle'. Critique: one-dimensional ecology. *Bulletin of the Atomic Scientists* 28 (5), 16-27.
- Gallopin, G. (2003). *A systems approach to sustainability and sustainable development* (Project NET/00/063). Economic Commission for Latin America, Sustainable Development and Human Settlements Division.
- Gaurav, K. (2026). India's drive to net zero emissions: Balancing growth with sustainability. In D.A.K. Dawood, Noushad C., G.A. Wani, and S.A. Kumar (Eds.), *Seeds of Renewal: Ethical Business, Conscious Finance and Human-Centred Innovation for a Living, Regenerative Future* (pp. 192-202). Alborear (OPC).
- Gupta, S. (2015). Decoupling: A step toward sustainable development with reference to OECD countries. *International Journal of Sustainable Development & World Ecology*, 22(6), 510-519. <https://doi.org/10.1080/13504509.2015.1088485>
- Haberl, H., Wiedenhofer, D., Virág, D., Kalt, G., Plank, B., Brockway, P.,... Creutzig, F. (2020). A systematic review of the evidence on decoupling of GDP, resource use and GHG emissions, part II: Synthesizing the insights. *Environmental Research Letters*, 15(6), 065003. <https://doi.org/10.1088/1748-9326/ab842a>
- Khosla, A., Niazi, Z., Nagrath, K., Thakur, M., Dewan, C., Gomez, F., Hennicke, P., O'brien, M., & Wilts, H. (2014). *Decoupling growth from resource consumption* (Background Paper). 2nd Indo-German Expert Group Meeting on Green and Inclusive Economy.
- Khoury, E. (13 June 2022). *South Asia: A frontier for sustainability on a dying planet*. LSE South Asia Centre.
- Lee, K.-H., & Min, B. (2014). Globalization and carbon constrained global economy: A fad or a trend? *Journal of Asia-Pacific Business*, 15(2), 105–121. <https://doi.org/10.1080/10599231.2014.904181>
- Lin, S., Beidari, M., & Lewis, C. (2015). Energy consumption trends and decoupling effects between carbon dioxide and gross domestic product in South Africa. *Aerosol and Air Quality Research*, 15, 2676–2687. <https://doi.org/10.4209/aaqr.2015.04.0258>
- Lv, Y., Tang, W., & Ding, Y. (2024). Industrial energy consumption and carbon emission decoupling study and driving factor analysis: A case study of Sichuan Province, China. <https://doi.org/10.21203/rs.3.rs-5330449/v1>
- Murthy, K.V. B., & Gambhir, S. (2018). Analyzing environmental Kuznets curve and pollution haven hypothesis in India in the context of domestic and global policy change. *Australasian Accounting, Business and Finance Journal* 12(2), 134-156. <https://doi.org/10.14453/aabf.v12i2.9>

- OECD (2002). *Indicators to measure decoupling of environmental pressure from economic growth*. Organisation for Economic Co-operation and Development.
- OECD (2005). *Environment at a glance: OECD environmental indicators*. OECD Publishing. Organisation for Economic Co-operation and Development.
- Ozcelik, O., Bardakci, H., Barut, A., Usman, M., & Das, N. (2024). Testing the validity of pollution haven and pollution halo hypotheses in BRICMT countries by Fourier Bootstrap AARDL method and Fourier Bootstrap Toda-Yamamoto causality approach. *Air Quality, Atmosphere, & Health*, 17(7), 1491–1504. <https://doi.org/10.1007/s11869-024-01522-5>
- Parrique T., Barth J., Briens F., C. Kerschner, Kraus-Polk A., Kuokkanen A., Spangenberg J.H. (2019). Decoupling debunked: Evidence and arguments against green growth as a sole strategy for sustainability. European Environmental Bureau. eeb.org/decoupling-debunked
- Quaye, E., Yamoah, F. A., Patro, P. K., & Acquaye, A. (2025). Decoupling economic growth from climate change: Unravelling the multi-dimensional dynamics of consumption-based emissions. *Journal of the Operational Research Society*, 77(1), 240–256. <https://doi.org/10.1080/01605682.2025.2483782>
- Rahman, M. M., Saidi, K., & Mbarek, M. B. (2020). Economic growth in South Asia: The role of CO2 emissions, population density and trade openness. *Heliyon*, 6(5), e03903. <https://doi.org/10.1016/j.heliyon.2020.e03903>
- Rani, T., Rehman, S. A. U., & Prisca, K. (2025). Assessing South Asia's environmental-economic nexus: Green investments, green electricity and green technology innovation through combined quantile regression. *Environmental Progress & Sustainable Energy*, (e70113). <https://doi.org/10.1002/ep.70113>
- Sanyé-Mengual, E., Secchi, M., Corrado, S., Beylot, A., & Sala, S. (2019). Assessing the decoupling of economic growth from environmental impacts in the European Union: A consumption-based approach. *Journal of Cleaner Production*, 236(117535), 117535. <https://doi.org/10.1016/j.jclepro.2019.07.010>
- Shahbaz, M., Mallick, H., Mahalik M.K., & Loganathan, N. (2015). Does globalization impede environmental quality in India? *Ecological Indicators*, 52, 379-393. <https://doi.org/10.1016/j.ecolind.2014.12.025>
- Smarzynska, B. K., & Wei, S.-J. (2001). Pollution havens and foreign direct investment: Dirty secret or popular myth? (Policy Research Working Paper No. 2673). The World Bank. <https://doi.org/10.1596/1813-9450-2673>
- Tapio, P. (2005). Towards a theory of decoupling: Degrees of decoupling in the EU and the case of road traffic in Finland between 1970 and 2001. *Transport Policy*, 12, 137–151.
- Temurshoev, U. (2006). *Pollution haven hypothesis or factor endowment hypothesis: Theory and empirical examination for the US and China* (CERGE-EI Working Paper Series 292). The Center for Economic Research and Graduate Education - Economics Institute, Prague.
- Tenaw, D., & Hawitibo, A. L. (2021). Carbon decoupling and economic growth in Africa: Evidence from production and consumption-based carbon emissions. *Resources, Environment and Sustainability*, 6, 100040. <https://doi.org/10.1016/j.resenv.2021.100040>
- Umpfenbach, K. (2013). *Decoupling growth from resource use and environmental impacts*. DYNAMIX Common Approach, Ecologic Institute. www.dynamix-project.eu
- UNEP (2011). *Decoupling natural resource use and environmental impacts from economic growth* (A Report of the Working Group on Decoupling to the International Resource Panel). United Nations Environment Programme (UNEP).

- Wan, L., Wang, Z.-L., & Ng, J. (2016). Measurement research on the decoupling effect of industries' carbon emissions—based on the equipment manufacturing industry in China. *Energies*, 9(11), 921. <https://doi.org/10.3390/en9110921>
- Wang, H., Zhao, S., Wei, Y., Yue, Q., & Du, T. (2018). *Measuring the decoupling progress in developed and developing countries*. In Proceedings of the 8th International Conference on Management and Computer Science (ICMCS 2018) (pp. 377–381). Atlantis Press. <https://doi.org/10.2991/icmcs-18.2018.77>
- Wang, W., Zhu, X., Kao, X., & Wei, H. (2024). Decomposition and decoupling analysis between economic growth and carbon emissions at the regional level: Evidence from six central provinces, China. *PloS One*, 19(9), e0305769. <https://doi.org/10.1371/journal.pone.0305769>
- Xu, M., Yang, X., Deng, L., Liao, X., Niu, Z., & Hao, L. (2024). Decoupling state of urban development and carbon emissions and its driving factors and predictions: A case study of Chengdu metropolitan area. *Ecological Informatics*, 82(102692), 102692. <https://doi.org/10.1016/j.ecoinf.2024.102692>
- Yareмова, M. I., & Mytروفanova, A. S. (2022). Decoupling as a measurement of the environmental impact of economic growth. *Scientific Bulletin of Mukachevo State University Series "Economics"*, 9(3), 30-39. [https://doi.org/10.52566/msu-econ.9\(3\).2022.30-39](https://doi.org/10.52566/msu-econ.9(3).2022.30-39)
- Zugravu, N., & Kheder, S. B. (2008). *The pollution haven hypothesis: A geographic economy model in a comparative study* (Working Paper 232). Fondazione Eni Enrico Mattei. <https://services.bepress.com/cgi/viewcontent.cgi?article=1241&context=feem>

Appendix Table A: Descriptive Statistics

Variable	Obs	Mean	Std. Dev.	Min	Max
CO2_I	238	254.1329	602.5007	.0946	3014.523
Population_P	238	2.21e+08	4.01e+08	224762	1.44e+09
GDPpc_A	238	2399.609	2559.955	422.7247	11439.54
Tech_T	156	5.019615	3.620639	1.55	19.34
Urban_E1	238	31.29566	11.45118	14.57395	66.54329
Trade_E2	238	51.50865	23.59974	15.50626	162.2434

Appendix Table B: Descriptive Statistics (Log Transformed)

Variable		Mean	Std. Dev.	Min	Max	Observations
ln_I	overall	2.733533	2.694683	-2.358098	8.011197	N = 238
	between		2.816195	-.4494578	7.233986	n = 7
	within		.6592963	.754939	4.110877	T = 34
ln_P	overall	16.9483	2.770456	12.3228	21.08657	N = 238
	between		2.980693	12.73171	20.86965	n = 7
	within		.1672845	16.52397	17.38964	T = 34
ln_A	overall	7.373552	.8544297	6.046721	9.344831	N = 238
	between		.8285188	6.504143	8.946526	n = 7
	within		.3730784	6.550109	8.164637	T = 34
ln_T	overall	1.407296	.6237373	.4382549	2.962176	N = 156
	between		.64412	.7410863	2.478008	n = 7
	within		.1620564	1.063454	1.891464	T = 22.2857
ln_E1	overall	3.383964	.3418372	2.679236	4.197853	N = 238
	between		.2884368	2.832045	3.75925	n = 7
	within		.2126996	2.608471	3.822566	T = 34
ln_E2	overall	3.842318	.448836	2.741244	5.089098	N = 238
	between		.4013306	3.411547	4.436157	n = 7
	within		.2506281	3.055	4.752845	T = 34

Appendix Table C: Correlation Matrix

	ln_I	ln_P	ln_A	ln_T	ln_E1	ln_E2
ln_I	1.0000					
ln_P	0.9422*	1.0000				
	0.0000					
ln_A	-0.3684*	-0.6221*	1.0000			
	0.0000	0.0000				
ln_T	-0.1503	-0.1045	-0.3782*	1.0000		
	0.0611	0.1943	0.0000			
ln_E1	0.0288	-0.0325	0.0173	0.4159*	1.0000	
	0.6580	0.6183	0.7906	0.0000		
ln_E2	-0.6700*	-0.7353*	0.4916*	0.3317*	-0.0679	1.0000
	0.0000	0.0000	0.0000	0.0000	0.2972	

Appendix Table D: Variance Inflation Factor (VIF)

Variable	VIF	1/VIF
ln_P	3.46	0.288747
ln_A	3.15	0.317460
ln_E2	2.75	0.364131
ln_T	2.38	0.420910
ln_E1	1.45	0.688856
Mean VIF	2.64	

Appendix Table E: Pesaran CD Test

Variable	CD-test	p-value	average joint T	mean ρ	mean abs(ρ)
ln_I	25.537	0.000	34.00	0.96	0.96
ln_P	25.737	0.000	34.00	0.96	0.96
ln_A	25.66	0.000	34.00	0.96	0.96
ln_T	9.735	0.000	22.05	0.45	0.87
ln_E1	23.608	0.000	34.00	0.88	0.88
ln_E2	.954	0.340	34.00	0.04	0.30

Note: *Ho: Existence of cross-sectional independence*

Appendix Table F: Panel Co-integration Test Results

Test	Statistic	With ln_T (6 Variables)	p-value	Without ln_T (5 Variables)	p-value	Decision
Westerlund (2007)	Gt	0.995	0.995	-		No Co-integration with T
	Ga	1.000	1.000	-		
	Pt	1.000	1.000	-		
	Pa	1.000	1.000	-		
Pedroni (1999, 2004)	Modified PP t	-2.07	0.0190**	-0.89	0.1867	Co-integration without T
	Phillips-Perron t	-0.99	0.1599	-2.67	0.0037***	
	ADF t	-1.05	0.1463	-2.44	0.0074***	
Kao (1999)	Modified Dickey-Fuller t	-0.45	0.326	-1.71	0.0436**	Strong Co-integration without T
	Dickey-Fuller (DF) t	-0.92	0.178	-2.26	0.0120**	
	ADF t	-0.98	0.163	-2.27	0.0119**	
	Unadjusted Modified DF	-0.89	0.186	-2.57	0.0050***	
	Unadjusted DF	-1.02	0.153	-2.63	0.0044***	

Note:

1. **p<0.05, ***p<0.01
2. Westerlund with lags (1) leads (0)
3. With ln_T: N=156 (missing data); Without ln_T : N=238 (balanced)
4. Pedroni modified PP is significant at 5% with T (weak co-integration), however, PP and ADF fail
5. Without T, 2 out of 3 Pedroni and 5 out of 5 Kao tests are significant at 5% and 1%. This justifies main Model: ln_I=f (P, A, E1, E2)