Journal of Business Insight and Innovation
Volume 5 Issue 8, 2026
ISSN-p: 3006-2284, ISSN-e: 3006-0982
https://insightfuljournals.com/

GREEN FINANCE, SOCIOECONOMIC DRIVERS, AND CARBON EMISSIONS IN ASIA: EVIDENCE FROM THE STIRPAT MODEL

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DOI: https://doi.org/10.63544/jbii.v5i8.143

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Article History:
Received: 09.07.2026
Accepted: 25.07.2026
Published: 07.08.2026

Abstract

This study has examined the determinants of CO_2 emissions in selected Asian countries through the use of STIRPAT. An extended version of the STIRPAT framework is used to include green finance development, income inequality, education, population growth, trade openness, and urbanisation as significant factors in per capita CO_2 emissions. Panel data is used for selected high-, upper-middle-, lower-middle- and low-income Asian countries, and the GMM estimation technique is employed for analysis. From the empirical findings, it can be seen that green finance development has significant negative effects on CO_2 emissions in all income groups, and the effect is stronger in lower-income countries. However, factors that lead to increasing carbon emissions vary among income groups. Trade openness and urbanisation are the major factors contributing to rising carbon emissions among high- and upper-middle-income countries. On the other hand, income inequality, population growth and increased consumption due to education have more significant positive impacts on CO_2 emissions in lower-middle- and low-income countries. The results also imply that green finance is not enough in decreasing carbon emissions. It should be complemented by certain policy actions and reforms to meet the needs of each country.

Keywords: Green Finance; Carbon Emissions; Environmental Kuznets Curve; Income Inequality.

1. Introduction

Climate change is considered the greatest environmental threat of this time and has a significant impact on ecosystems, public health, food security and freshwater resources. The impacts of climate change are felt all over the world through droughts, floods, and storms, which have mainly been caused by human activities such as the burning of fossil fuel. Asia is one of the largest carbon emitters in the world, as emissions have significantly affected its environment and economy. The major factors contributing to the adverse situation include high population density, urbanization and industrialization rates.

Green finance has emerged as one of the key policy tools that play a major role in channelling the flow of money towards environmental sustainability. This is done through instruments such as green bonds, green loans, sustainability-based financing, and environmentally oriented foreign investment. However, it remains unknown whether green finance results in reduced emissions and how these changes depend on the income level of the nation, especially in the very different economies of Asia.

The answer to this question demands an analytical framework that can separate the net impact of financial, demographic, and structural factors on environmental outcomes from other controlling factors that together influence emissions. The STIRPAT model, formulated by Dietz and Rosa (1994) as a statistically

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Volume 5 Issue 8, 2026
ISSN-p: 3006-2284, ISSN-e: 3006-0982
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testable variant of the IPAT equation, can serve precisely this purpose. This article employs the extended STIRPAT model to analyze the interaction between the development of green finance, income inequality, educational level, population dynamics, openness, and urbanization in influencing per capita CO_2 emissions in selected Asian countries and to assess how it varies in richer and poorer nations in the region.

This study makes three main contributions to the literature. First, it constructs a composite Green Finance Development Index based on renewable energy consumption, public-private energy investment, and green foreign direct investment and does not use a single and narrow indicator like green bond issuance to measure the financial channel. Second, it incorporates this index into the STIRPAT framework, along with the other factors of income inequality, education, population growth, trade openness, and urbanization, which represent socioeconomic and structural drivers together, and not separately. Third, and most importantly, it estimates the model separately for the high-, upper-middle-, lower-middle-, and low-income economies in Asia, allowing it to determine the systematic variation in the emissions-reducing potential of green finance and the relative importance of the other drivers, with a country's stage of development. The study provides evidence that can be used to develop differentiated climate finance policy in a very diverse region. The rest of the paper is organized as follows. Section 2 is a review of the relevant literature on STIRPAT, green finance, and carbon emissions. Section 3 presents the theory underlying the model, its empirical specification, and the method of estimation. The results of the empirical analysis are presented and discussed in Section 4. Section 5 concludes with a summary of findings.

2. Literature Review

Researchers have widely applied the STIRPAT approach in the empirical environmental economics literature to study human causes of environmental degradation. STIRPAT extends the original deterministic IPAT identity to a stochastic regression model, providing the opportunity to test hypotheses regarding the impact of macroeconomic, financial, and structural factors on per capita emissions. In this context, researchers initially focused their empirical attention on the environmental consequences of traditional financial development. Guo et al. (2019) applied an extended STIRPAT model to investigate the relationship between financial development and CO_2 emissions in China (1975-2015). The study showed positive relationships of financial development as measured by the financial development scale, financial efficiency, and stock trading volume with CO_2 emissions. It also showed negative relationships of financial development as measured by market capitalization with CO_2 emissions. Similarly, Goel et al. (2019) tested the STIRPAT model on the Chinese panel data and concluded that trading increased emissions, whereas financial efficiency decreased their level.

With the change in the global climate policy landscape towards sustainable capital allocation, researchers have modified the STIRPAT model to assess green finance mechanisms. Sun et al. (2023) employed the STRIPAT model alongside the system GMM method to find out the influence of green financing and renewable energy on Chinese provinces from 2010 to 2021. The study found out that green financing played an influential role in reducing emissions in the nation; however, the reduction was observed in the eastern and western provinces of China. Ahmed et al. in 2022 conducted a study using the STRIPAT model to find out the green energy index, green finance, and energy efficiency in ASEAN member countries between 2002 and 2018. The findings from the study indicate that green bonds could contribute to the reduction of CO_2 emissions by directing funds towards green projects. In connection with these findings, Rasoulinezhad and Taghizadeh-Hesary (2022) noted that using certain green financial channels may reduce the cost of capital for the implementation of clean technologies and thus decrease the dependence on fossil fuels.

The key structural and demographic factors, such as income inequality, education, trade openness, and urbanization, are often integrated with financial channels and the Environmental Kuznets Curve (EKC) hypothesis in modern extensions of the STIRPAT model. Arshad et al. (2021) used both the STIRPAT and EKC frameworks for 80 countries over the period of 1990-2017. The researchers found that there is a U-shaped relationship between economic growth and environmental quality, with urbanization being an emissions-positive determinant and governance and technological development being emissions-negative determinants. Building on these structural dynamics, Sadorsky (2014) demonstrated that the carbon intensity of emerging economies first rises with rapid urbanization because of the construction of large amounts of infrastructure and energy use.

Liddle and Lung (2010) noted, however, that with urban maturity, economies of scale may be realized from public transport systems and energy-efficient building codes. Socio-economic aspects of STIRPAT are also extended to include inequality and human capital. Grunewald et al. (2017) showed that income inequality can lead to higher emissions in high-poor countries, where the poor are more dependent on low-cost, high-polluting energy sources, but to lower per capita emissions in high-income countries, where high inequality is associated with high concentration of consumption in a smaller geographic area. Additionally, in environmental models, education has two mechanisms. As Pablo-Romero and Sánchez-Braza (2015) and Zafar et al. (2019) have pointed out, an increase in literacy leads to an increase in industrial employment and living standards, which in turn leads to an increase in energy consumption in the short run

Lastly, the effect of trade openness in STIRPAT is often explained by the Pollution Haven Hypothesis (Pollution Haven Hypothesis, 2004; Antweiler et al., 2001) which suggests that international trade redirects carbon-intensive production to the emerging economies with less stringent regulations. These theoretical and empirical contributions provide a sound basis to understand the impact of green financial resources on the decarbonization pathways at different income levels depending on the socioeconomic structures of each country.

3. Methodology

This section outlines the analytical framework used to examine the drivers of per capita CO_2 emissions in the selected Asian economies. It first presents the theoretical foundation of the STIRPAT model, then specifies the empirical model and describes the variables and finally details the estimation technique used to generate the results reported in Section 4.

3.1 Theoretical Basis: From IPAT to STIRPAT

The STIRPAT model is based on the IPAT identity proposed by Ehrlich and Holdren (1971) that represents the environmental impact as the product of Population, Affluence, and Technology. IPAT described the environmental impact as a function of these three factors, but it assumed that each factor had a strictly proportional impact on the environment, an assumption that could not be statistically tested. To overcome this limitation, Dietz and Rosa (1994, 1997) modified IPAT to a stochastic form that can be estimated by regression analysis, enabling researchers to test hypotheses about the true (not assumed) magnitude of each driver's effect and to include more variables than the original three, which were theoretically justified .STIRPAT is a theoretical model based on the underlying principle of Structural Human Ecology the logic of the IPAT identity, and an empirical research program that is separate from IPAT's formal accounting system, as Knight (2009) explains. It gives STIRPAT flexibility, which allows it to become the leading methodology in environmental economics to test the drivers of ecological impact and to find out how policy could be influenced by knowing which human activities affect the environment.

3.2 Model Specification

In this paper, STIRPAT model is modified to account for the mechanism through which green financing and socio-economic factors influence climate variables. In addition to population, the model considers green financing development and income inequality as affluence factors, while education is considered an indirect proxy for the technological factor since high levels of education encourage innovations and environmental consciousness. Trade openness and urbanisation are used as other structural control variables. The proposed model is specified as follows:

$$CO_{2it} = \beta_0 + \beta_1\, GFD_{it} + \beta_2\, IE_{it} + \beta_3\, Edu_{it} + \beta_4\, Pop_{it} + \beta_5\, URB_{it} + \beta_6\, TO_{it} + \varepsilon_{it} \text{……. } Eq\ (1)$$

where CO_2it denotes annual per-capita carbon dioxide emissions for country i at time t; GFD is Green Finance Development, the affluence-related construct of interest, which is measured empirically using the Green Finance Index (GFI) as a proxy; IE is income inequality; Edu is education; Pop is the population growth

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Volume 5 Issue 8, 2026
ISSN-p: 3006-2284, ISSN-e: 3006-0982
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rate; URB is urbanisation; and TO is trade openness. The intercept β0 is absorbed into country-specific fixed effects within the panel GMM framework and, therefore, carries no independent economic interpretation.

Climate change is the dependent variable of the study, proxied by annual per capita CO_2 emissions in metric tons. It is selected because of its well-established causal relationship with global warming and its availability and comparability across countries and years. The Green Finance Development Index is an independent variable, which is a composite variable calculated through principal component analysis from the following three indicators: percentage of renewable energy consumption relative to total final energy consumption, public-private investment in the energy sector, and foreign direct investment relative to GDP. Other dependent variables include the Gini coefficient for measuring income inequality, the adult literacy rate as the measure of education level, annual population growth rate as a proxy of population, and urban share and percentage of trade to GDP as proxies for urbanization and trade openness, respectively. The data on all variables is taken for the period 2000-2023.

The sample consists of 18 selected Asian economies that are both important in global emissions and vulnerable to climate risk, and it is split into two income groups for comparison. Singapore, South Korea, Japan, China, Russia, Malaysia, the Maldives, and Thailand are part of the high-income and upper-middle-income groups. Sri Lanka, Indonesia, the Philippines, Bangladesh, India, Pakistan, Nepal, Afghanistan, Cambodia and Myanmar are in the lower-middle-income and low-income group. This classification is based on the assumption that the depth of a country's finances is closely linked to its income level and its technological capacity to mobilize and utilize green financial resources, as well as its regulatory quality.

3.3 Estimation Technique

The model is estimated using the Panel Generalized Method of Moments (GMM) with fixed effects. GMM is preferred over static estimators such as pooled OLS or standard fixed/random effects models because carbon emissions exhibit strong persistence over time, meaning current emissions are influenced by past emissions, a dynamic relationship that static estimators cannot adequately capture without introducing dynamic panel bias. GMM addresses this by using lagged values of the dependent and endogenous explanatory variables, including green finance development, trade openness, and education, as internal instruments, thereby correcting for endogeneity arising from reverse causality and simultaneity between these variables and emissions. The validity of the instrument set is confirmed using the Hansen-Sargan J-statistic, and the Arellano-Bond AR(2) test is used to check for second-order serial correlation in the first-differenced residuals; a non-significant AR(2) statistic ($p > 0.10$) indicates that the moment conditions underlying the GMM estimator are correctly specified. First-order (AR(1)) correlation is expected by construction under first-differencing and is not itself evidence of misspecification.

4. Results

This section presents the empirical findings of the extended STIRPAT model. Results are discussed first for the full sample of selected Asian countries, followed by separate estimations for high- and upper-middle-income countries and for lower-middle- and low-income countries, in order to capture how the drivers of carbon emissions vary systematically across different stages of economic development.

4.1 Overall Results for Selected Asian Countries

Table 1 reports the GMM estimation results for the full sample of selected Asian countries.

Table 1

GMM Estimation Results for the Full Sample of Selected Asian Countries

Variable	Coefficient	Std. Error	t-Statistic	Prob.
GFI	-0.2528	0.0795	-3.1786	0.0016
IE	-0.0472	0.0329	-1.4344	0.1523
EDU	0.0276	0.0120	2.2964	0.0222
POP	-0.0463	0.0369	-1.2553	0.2101
TO	0.0094	0.0025	3.7695	0.0002
URB	0.0247	0.0218	1.1334	0.2577

Journal of Business Insight and Innovation
Volume 5 Issue 8, 2026
ISSN-p: 3006-2284, ISSN-e: 3006-0982
https://insightfuljournals.com/

Variable	Coefficient	Std. Error	t-Statistic	Prob.
Adjusted R-squared	0.9884		J-Stats	11.1720
			Probability	0.0832
AR(2) test			p-value	0.9934

The coefficient of the Green Finance Index is -0.2528, which is statistically significant ($p<0.01$), indicating that a one-unit increase in green finance activities will decrease annual per capita CO_2 emissions by approximately 0.25 metric tons. This points out the importance of green bonds, green oans, and environmentally related financial policies in reducing emissions in Asian economies. Education is positively and significantly related to emissions (coefficient = 0.0276, $p < 0.05$), as is the case with the increase in literacy, which increases economic participation and living standards before the environmental-awareness benefits catch up. Trade openness also has a positive and significant sign (coefficient = 0.0094, $p < 0.01$), corresponding to the emissions produced with the expansion of production, transportation, and industrial activity. At the overall level, there are no statistically significant effects for income inequality, population growth, and urbanization. The model accounts for about 99% of the variation in emissions (R-squared = 0.9884), and the Arellano-Bond AR(2) test ($p = 0.9934$) shows no evidence of second-order serial correlation. The Hansen J-statistic ($p = 0.083$) also indicates that the instruments used are valid.

4.2 High- and Upper-Middle-Income Asian Countries

Table 2 reports the GMM estimation results for high-income and upper-middle-income Asian countries.

Table 2

GMM Estimation Results for High- and Upper-Middle-Income Asian Countries

Variable	Coefficient	Std. Error	t-Statistic	Prob.
GFI	-0.4585	0.1802	-2.5448	0.0119
IE	-0.0342	0.0173	-1.9748	0.0500
EDU	-0.0017	0.0131	-0.1263	0.8997
POP	-0.1912	0.0783	-2.4408	0.0157
TO	0.0143	0.0041	3.4807	0.0006
URB	0.1097	0.0373	2.9375	0.0038
Adjusted R-squared	0.9642		J-Stats	3.8658
			Probability	0.6948
AR(2) test			p-value	0.8054

The impact of green finance is significantly greater in richer Asian economies, with a coefficient of -0.4585 ($p < 0.05$), which means that a unit increase in green finance leads to a reduction of around 0.46 metric tons of per capita emissions. Income inequality (-0.0342, $p = 0.05$) and population growth (-0.1912, $p < 0.05$) are both negatively and significantly correlated with emissions, and these findings are consistent with the economies of scale of dense, well-developed urban areas, and with lower-income households in wealthier countries using relatively small amounts of energy. Statistical evidence shows education has no effect ($p = 0.90$), indicating that in societies with a high level of literacy and institutions with high environmental norms, additional education does not meaningfully affect emissions. In contrast, the coefficients of trade openness (0.0143, $p < 0.001$) and urbanization (0.1097, $p < 0.01$) are both strong, positive, and significant, suggesting that export-oriented manufacturing, logistics, and rapid urbanization continue to be significant sources of emissions in financially mature economies. The model accounts for about 97% of the variation in emissions (R-squared = 0.9642), the Arellano-Bond AR(2) test shows no evidence of second-order serial correlation ($p = 0.8054$), and the GMM instruments are valid (J-statistic $p = 0.695$).

Journal of Business Insight and Innovation
Volume 5 Issue 8, 2026
ISSN-p: 3006-2284, ISSN-e: 3006-0982
https://insightfuljournals.com/

4.3 Lower-Middle- and Low-Income Asian Countries

Table 3 reports the GMM estimation results for lower-middle-income and low-income Asian countries.

Table 3

GMM Estimation Results for Lower-Middle- and Low-Income Asian Countries

Variable	Coefficient	Std. Error	t-Statistic	Prob.
GFI	-1.0087	0.4727	-2.1336	0.0339
IE	0.1626	0.0366	4.4422	0.0000
EDU	0.0125	0.0040	3.1241	0.0020
POP	0.0737	0.0254	2.8923	0.0042
TO	0.0035	0.0019	1.7881	0.0751
URB	0.0157	0.0175	0.8960	0.3712
Adjusted R-squared	0.9279		J-Stats	2.9671
			Probability	0.5633
AR(2) test			p-value	0.8543

The coefficient of green finance is -1.0087, which indicates that the development of green finance has a greater effect on the decrease of emissions in this income group compared to that in rich countries. The study points out that a marginal increase in green finance can have a large environmental payoff in the countries where clean infrastructure is lacking. Income inequality is positively and significantly related to emissions. High-income groups have more carbon-intensive consumption patterns. Low-income groups have less efficient energy use, e.g., biomass, and increasing demand for energy due to population growth. The positive and significant relationship between education and emissions (0.0125, $p < 0.05$) is attributed to the fact that the aspirations and industrial employment opportunities in higher-income contexts are greater than the environmental-awareness benefits of education. Trade openness has a positive but marginally significant relationship ($p = 0.075$), and urbanization has no significant relationship, indicating that many urban centres in these economies continue to be dependent on relatively low-energy informal economic activity. The model accounts for about 93% of the variation in emissions (R-squared = 0.9279), the Arellano-Bond AR (2) test shows no evidence of second-order serial correlation ($p = 0.8543$), and the instruments are valid (J-statistic $p = 0.563$).

4.4 Cross-Income Comparison

When comparing across income groups, the findings are consistent that green finance development is associated with a substantial reduction in overall carbon emissions across all income groups, with the impact being larger in the low- and lower-middle-income countries than in the high- and upper-middle-income countries. The difference in impact is roughly 1.01 metric tons per unit of increase in green finance in low- and lower-middle-income countries, compared with 0.46 metric tons in high- and upper-middle-income countries. Beyond this shared result, the structural and socioeconomic drivers of emissions diverge sharply by income level. In wealthier economies, trade openness and urbanization are the dominant emissions-increasing forces, while income inequality and population growth act to reduce per-capita emissions through economies of scale and shifting consumption patterns. In poorer economies, the reverse holds: income inequality, population growth, and education-linked consumption all push emissions upward, while trade openness and urbanization play a comparatively muted role.

5. Conclusion

In this study, the extended STIRPAT model has been applied to investigate the determinants of carbon dioxide emissions across different income groups of selected Asian countries. The results reveal that the development of green finance has a significant effect on lowering CO_2 emissions per capita in all income brackets, especially in low-income economies where clean infrastructure is still underdeveloped. But green finance is not enough for decarbonisation. Trade openness and urbanisation are still driving emissions growth in higher-income economies, while income inequality, population growth and the early-stage impacts of education are still important in lower-income economies. In general, a successful climate policy in Asia must include an increase in green finance and structural reforms that are specific to the level of economic development of the country.

Author Contributions

All authors participated in ideation, development, and writing the manuscript. All authors read and approved the final manuscript.

Conflict of Interest Statement

The authors declare that there is no conflict of interest regarding the publication of this article.

Funding Statement

The authors did not receive financial support from any funding agency or external organization for the research, authorship, or publication of this article.

Informed Consent

Informed consent was obtained from all participants.

Data Availability

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

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