



Barera Arshad¹, Taskeen Rubab², Ayesha Siddiqui³, Aena Abid⁴

¹Center for Integrated Mountain Research, University of the Punjab, Lahore, Pakistan

Email: breeramehar59@gmail.com

²Department of Economics, Government College University, Faisalabad, Pakistan

Email: taskeenrubab700@gmail.com

³School of Economics, University of the Punjab, Lahore, Pakistan

Email: siddiquiayesha1115@gmail.com

⁴Department of Economics, Lahore College for Women University, Pakistan Email: aenaabid213@gmail.com

KEYWORDS	ABSTRACT
Greenhouse Gas Emissions; Sustainable Development; Asian Economies; Climate Change; CCEMG; panel heterogeneity	The rising economic boom in Asia is beginning to meet a more difficult challenge: how to grow an economy that is also a long-term wealth producer and has continued rising emissions of greenhouse gases? This is particularly relevant in an area where the development rate, carbon intensity and environmental challenges are not happening simultaneously across the countries. The present study investigates the long-term relationship between climate change pressure and sustainable development in 21 selected Asian economies for the period 2000–2021. Sustainable development is evaluated by the modified adjusted net savings indicator SD*. The analysis uses a unit root test by CIPS, a Westerlund cointegration test, a Pesaran–Yamagata slope heterogeneity test, and a Common Correlated Effects Mean Group estimator with a bootstrap inference. The findings show that the cross-sectional dependence is high and the heterogeneity of slopes is significant. While the climate change pressure has negative and statistically insignificant relationship, and the economic development coefficient is positive and statistically significant for sustainable development. The findings suggest that sustainability relationships are not the same across Asian economies, highlighting the importance of country-specific climate and development strategies.
ARTICLE HISTORY Date of Submission: 09-03-2026 Date of Acceptance: 01-04-2026 Date of Publication: 08-04-2026	 2026 Journal of Social Research Development
Correspondence	Barera Arshad
Email:	breeramehar59@gmail.com
DOI	https://doi.org/10.59075/jsrd.v7i2.565
Volume/Issue	7(2), 2026, 56-80

Introduction

Climate change and sustainable development are becoming harder to deal with as distinct policy issues. Economic growth can boost living standards and provide resources for investment but growth that continues to be reliant on carbon-intensive production may also result in increased environmental harm, deterioration of natural capital, and future costs to households and governments (Wang, Gillani, Sharif, et al., 2025). Such tensions are especially significant in Asia, where the continent's rapid industrialization, urbanization, and escalating energy consumption, coupled with significant income disparities, has generated a variety of Asian development trajectories. Recent evidences showed that emissions of GHG in Asia made up over 40% of global GHG emissions in 2023 and several of the top GHG emitters are in Asia (H. Zhang et al., 2026). Meanwhile climate stressors are increasingly being felt, such as heatwaves, flooding, droughts, glacier retreat and rising ocean temperatures. The World Meteorological Organization (WMO) has observed significant and persistent climate threats throughout Asia and noted that the economic, environmental and human impacts of these threats are increasing (Organization, 2026).

It's a similarly dire dilemma for sustainability. While significant strides have been made in multiple social and economic indicators, there is still much that remains to be accomplished for the Asia-Pacific region to meet many of the Sustainable Development Goals (SDGs). The United Nations Economic and Social Commission for Asia and the Pacific's latest regional assessment indicates 103 of 117 measurable SDG targets will be off track by 2030. Recent scenario related research also indicates that climate and sustainable-development goals are linked but not automatically. For instance, H. Zhang et al. (2026) report that Asian climate action can deliver significant benefits for energy systems, air quality and health, while complementary policies that consider the national development context and transition costs are necessary for broader sustainability gains.

Climate pressure can affect sustainable development in various ways. The link between higher emissions and more energy and production intensive economic structures may result in income being earned in the short run but costs being borne to the environment in the long run. There are two channels that are related. First, high per-capita GHG emissions can be indicative of carbon intensive production and energy supply systems that may have environmental and natural-capital costs (Jiang et al., 2026). Second, climate hazards can inflict damage on infrastructure, agriculture, health and public goods, but this damage is only realized when the global climate forcing is combined with local exposure and vulnerability, not just with a country's own emissions in the present. The actions of climate hazards on development are shown in Bangladesh and South Asia (Adshead et al., 2024; Rana, 2025). The empirical analysis thus understands CC as an indicator of climate pressure based on the emission rather than a direct indicator of climate damage. The case studies from Bangladesh show that flooding and coastal erosion can negatively impact progress in multiple SDG areas, such as in the provision of infrastructure services for the vulnerable communities (Adshead et al., 2024). Likewise, recent South Asian studies reveal that the impacts of climate risks like extreme heat can be different across various places and different for different people, as adaptive capacity and country-specific conditions influence the magnitude of these

impacts (Rana, 2025). The results indicate that the climate pressure–development link is not necessarily the same in economies around Asia. It is important, therefore, to measure sustainable development in an appropriate manner. The traditional measures of economic activity, like gross domestic product, do not explicitly reflect the natural resources that are used up, the produced capital that is depreciated, the human capital that is invested, or environmental damage.

Adjusted net savings (ANS) is a more comprehensive capital-based measure that accounts for national savings beyond education expenditure, resource depletion and pollution damage. With this in mind, the aim of this project is to apply ANS as an empirical measure of long-term sustainability. Wei and Huang (2022) used ANS to explore the sustainable development in ten economies in Asia, and also observed that these two components, economic growth and renewable energy, played important roles in the sustainable development process. Recently, Khan et al. (2025) applied ANS in four South Asian economies, and found considerable long-term connections between sustainable development and various economic and environmental variables. However, ANS is not a definitive measure. However, Pezzey (2024) notes that more refinement might be needed as some human, knowledge, and natural capital are not captured in full. Therefore, it is important to understand that ANS is designed to be an informative exercise for sustainability and not a comprehensive indicator of all aspects of sustainable development.

Another measurement problem is when emissions are directly used as an explanatory variable. The damage from carbon dioxide emissions is already estimated and deducted from national savings in the World Bank's standard ANS indicator. Therefore, using a similar measure of emissions to describe unadjusted ANS might result in some mechanical co-linearity between the dependent and explanatory variables. To solve the problem, the present study proposes a modified sustainability indicator SD^* consisting of the original ANS indicator plus the World Bank carbon-dioxide damage component. The overall savings, human-capital, natural-resource depletion, and particulate-damage components of ANS are kept, but the deduction for the direct carbon damage is removed. This measure provides the opportunity to explore the connection between climate pressure and sustainability with less accounting dependency built-in.

The amount of literature on emissions, renewables and sustainability in Asia has grown, but there are some gaps. Much of the empirical research either looks at emission as the dependent variable, or at a very few countries or sectors. For instance, Wei and Huang studied the integration of renewable energy in ten Asian economies, and Khan et al. (2025) explored the situation of four countries in South Asia. Liu and Liu (2025) analyze the agricultural carbon footprints and sustainable development in nine countries in Asia, and highlight the fact that the relationships vary according to national contexts. Given this, the evidence emerging suggests there is significant variation, but there is limited cross-regional analysis of the effect of climate change pressure on capital-based sustainable development.

This study fills that void and looks at 21 Asian economies, ranging from Eastern, Southeast, Southern, Central and Western Asia, between the years 2000 and 2021. The term climate-change pressure in this study involves only a country's contribution to anthropogenic GHG emissions per

capita, but not its climate vulnerability, exposure or actual climate-related damages, and the term SD^* denotes modified adjusted net savings. Theoretically relevant controls such as GDP per capita, trade openness, urbanization, and natural-resource rents are included. The analysis is methodologically based on the premise that Asian economies are subject to the same regional and global shocks, but also have significant structural differences and environmental reaction. Second generation panel procedures are used to correct for cross sectional dependence and slope heterogeneity, and then a Common Correlated Effects Mean Group estimator is used.

Literature Review

Sustainable Development and Adjusted Net Savings

In sustainable development, economic growth needs to be part of the consideration of maintaining the assets required to underpin future wellbeing. The traditional measures of economic growth, such as GDP, offer valuable information on the state of the economy, but fail to capture the loss of natural resources, environmental degradation, nor human capital investment. To correct for some of this limitation, adjusted net savings (ANS), or genuine savings, may also be used to measure the economy's total capital base. It uses the conventional concept of net savings and adds investment on education, and subtracts natural-resource depletion and environmental damages. This has led to ANS being accepted as a recognized capital-based indicator of weak sustainability.

But empirical studies conducted early indicated that ANS is not a completely reliable indicator of sustainability. Using genuine savings to forecast future consumption, Ferreira and Vincent (2005) concluded that there was a stronger support for developing economies than developed ones, but that the forecasting power was limited. Pillarisetti (2005) also put forth that the World Bank measure is conceptually and empirically flawed, especially in the valuation of environmental assets. These criticisms do not invalidate ANS, but suggest that its interpretation must be linked to changes in comprehensive wealth and not to all aspects of sustainability.

Thereafter, studies were conducted to support its usefulness. Greasley et al. (2014) studied genuine savings over an extremely long time period and conducted a test that supports the view that it can serve as a forward-looking measure of future wellbeing. Hanley et al. (2015) surveyed the theoretical and empirical literature and explained the concept of genuine savings as an important country-level indicator that is based on the concept of accounting for wealth and weak sustainability. Boos (2015) also noted that the measurement decisions made for human capital, resource depletion, pollution, and population growth can significantly impact really estimated genuine savings. This discussion has been continued recently. Pezzey (2024) demonstrates that conventional ANS still needs to be tweaked as some aspects of human capital, knowledge capital, resource growth and productivity are not fully captured. McLaughlin et al. (2025) provide a further example of its enduring relevance as a long-run measure of wealth, by building up estimates back over more than a century. When taken together, this literature justifies the use of ANS and makes the case for the need for transparent adjustments when a specific component poses a problem for the question being addressed in the empirical study.

This is especially pertinent in the current study. The damage to carbon-dioxide is estimated by the software of the Standard ANS. If an emissions variable is used to explain ANS then part of the estimated relationship could be mechanical since carbon damage is already part of the dependent variable. The present study thus reintroduces the World Bank carbon-dioxide damage component into ANS and builds SD*, which will introduce the pressure of climate change into the model as an explanatory variable but without the direct accounting overlap.

Climate-Change Pressure and Sustainable Development

There are a number of links between climate pressure and sustainable development. High GHGs emissions are linked to intensive resource exploitation, industrial growth, transportation and fossil fuel-based production. These activities can generate present income but can also be detrimental to the environment, the climate, health, infrastructure, and natural capital (Wang, Gillani, Balsalobre-Lorente, et al., 2025; Wang et al., 2024). The impact on sustainable development is thus not only determined by the level of production but whether there is a sufficient economic benefit to offset losses of environmental and natural assets. Environmental concern also shapes public willingness to make economic sacrifices in support of green business practices, highlighting the social dimension of sustainability transitions (Gillani et al., 2026).

The literature on sustainable development based on a wealth indicator tends to confirm that sustainable development is linked to environmental degradation. Tokimatsu et al. (2019) integrated genuine savings into an integrated assessment framework and demonstrated that the results of a climate-policy evaluation can vary when the impacts on comprehensive wealth and future well-being are taken into account. Their analysis shows why environmental costs of climate change are relevant to capital-based approaches to sustainability. However, more direct empirical evidence comes from a study by Hunjra et al. (2023) of 42 developing countries between 2000 and 2020. They applied the adjusted net savings as a sustainable development indicator and CO₂ emissions as an indicator of environmental degradation, and concluded that the environmental degradation had a significant negative impact on the sustainable development. The results obtained were not affected when different panel estimators were used. This evidence is significant for the current study as both analyses take into account a wealth-based measure of sustainability, instead of the GDP or environmental-quality index only.

The findings from Asia are in line with the above, but also show significant differences between countries. In order to control for cross-sectional dependence and heterogeneity, Wei and Huang (2022) employed the ten Asian economies over 1990-2020 to study adjusted net savings through panel methods constructed to control for such. Their findings indicated that the factors of growth, finance and renewable energy have positive effects on sustainable development. While their core research was into energy structure, and not GHG emissions directly, the study underlines the need for understanding the impacts of common shocks and varying national responses when considering sustainability in Asian economies. Khan et al. (2025) offer more direct evidence for Bangladesh, India, Pakistan and Sri Lanka. They find a statistically significant and negative long run coefficient

for CO₂ emissions when using data from 2000–2022 and net savings as the dependent variable. Furthermore, their estimates show that GDP per capita and other macro-economic factors affect sustainable development, which further indicates that the assessment of environmental pressure must be included along with economic characteristics. Climate pressure can have an impact on wider sustainable-development outcomes as physical climate risks.

Rana (2025) reports that South Asian countries experience varying impacts of extreme heat and land-surface temperature on sustainable-development performance, depending on the country and its sustainable-development resilience. At a broader Asian scale, H. Zhang et al. (2026) demonstrate that the potential benefits of ambitious climate action go beyond emissions reductions, but that progress towards other dimensions of sustainability is also highly dependent on supportive development policies and country-specific conditions. The studies contribute to the perspectives that it is not expected to have the same climate-development relationship in all the Asian economies. From this evidence, the following major hypothesis is proposed:

H1: Higher climate-change pressure is associated with lower sustainable development in Asian economies.

Economic Development and Sustainable Development

Economic growth can contribute to sustainable saving if increased income boosts the ability to invest in physical capital, education, technological advancement and protection of the environment (Sharif et al., 2026; Yang, Shafiq, Nazir, et al., 2024; Yang et al., 2025). But high growth rates driven by reliance on environmental degradation and pollution may not achieve the same outcomes (Nazir et al., 2026; Sun et al., 2025; Yang et al., 2026). Empirical relationship thus is partly based on the growth structure. Koirala and Pradhan (2020) studied the relationship between per capita income and adjusted net savings in 12 Asian countries during 1990–2014 and concluded that there was positive and significant relationship between the two. They also found their results to be negative for natural-resource rents. This offers a strong regional argument to incorporate GDP per capita and resource dependence in sustainability models.

A positive impact of economic growth in adjusted net savings is also reported by Wei and Huang (2022) for Asian economies. Recently, Abid (2025) analyzed net savings with South Asian data for the period 1985–2023 and concluded that the increase in GDP growth had a positive impact on the adjusted net savings. Similar positive long-run coefficient of per capita GDP also is reported for South Asia by Khan et al. (2025). This body of evidence indicates that the path to sustainable accumulation of wealth lies in making economic gains productive and human capital, which can be achieved with higher income.

Trade Openness, Urbanization, and Sustainable Development

The impact of increased trade openness on sustainable development is not as well understood. More international trade can increase incomes, increase technology access, and increase resource

allocation – all of which can be beneficial for savings and investment. Concurrently, trade can promote "dirty" production, resource extraction, and energy use, especially in instances of lax environmental regulation (Xie et al., 2026; Yang, Shafiq, Sharif, et al., 2024). This uncertainty is reflected in the empirical results. The studies based on modified net savings have identified positive impacts of trade openness on environmental sustainability in some cases. Huo et al. (2022) founded with adjusted net savings as sustainability measure, that there was a positive effect of trade openness, while foreign investment with ANS found a positive contribution of trade openness. Razak et al. (2025) identified a negative long-run association between trade openness and adjusted net savings in the ASEAN economies, indicating that the sustainability impact of trade depends on the interaction between economic integration and the structure of domestic production and environmental protection measures. This is mixed evidence and provides some justification for giving trade a weighty control without a strong prior expectation on the coefficient of trade.

Urbanization is no exception. Concentrated urbanization can benefit productivity, provision of infrastructure, access to education and technological diffusion. But fast, unplanned urbanization can lead to higher energy consumption, traffic, pollution, and land and natural resource strain. Based on the adjusted net savings measure, Wang et al. (2022) showed that inclusive green growth is significantly reduced by urbanization for 64 economies in the Belt and Road Initiative between 2004 and 2019. They also reveal that the effect is related to governance and that urbanization does not automatically lead to unsustainability, but rather how urban expansion is managed can determine the outcome. These contrasting mechanisms are especially relevant in the current Asian sample of economies, which span the entire range of urbanization and development. Urbanization is thus controlled for and not necessarily assumed to have a negative or positive effect.

Natural-Resource Dependence and Sustainable Development

The genuine-savings framework is focused on the natural resource-sustainable development nexus. While natural capital is being depleted from the use of resources, sustainability can be maintained by effective transfer of resource rents into other productive assets. But, in practice, resource-dependent economies frequently encounter problems of transforming resource incomes into sustained human and produced capital (Sui et al., 2026).

Genuine savings is shown to be lower in more abundant resource areas, especially in lower institutional quality areas, by Dietz et al. (2007). They find that lower corruption has the potential of attenuating the negative impact of resource dependence on genuine saving. Similarly, Koirala and Pradhan (2020) find that net savings in Asian countries is negatively and significantly affected by natural-resource rents. New studies support this finding, but with caveats. Drawing on data covering 118 countries, van Krevel and Peters (2024) conclude that overall, energy-resource rents and exports tend to diminish genuine savings, but the impact is highly sensitive to the institutional quality of the country and to how the resource income is reinvested. Similarly, Ganhane and Stage (2024) note that the income flows from natural capital that are being depleted must be transformed into other capital. The results are especially relevant for the natural-resource rents

being used as a control variable in a heterogeneous Asian sample, which encompasses both a very resource-intensive economy as well as a relatively resource-poor economy.

Research Gap

There are several important determinants of sustainable development as identified in literature and three gaps are relevant to this study. The first is that a lot of the Asian literature looks at renewable energy, financial development, trade, or individual forms of environmental degradation and not at total greenhouse gas emissions per capita as a measure of climate change pressure. Second, some empirical studies employ the standard ANS indicator, even though CO₂ damage is a component of the construction of ANS. This then presents a measurement problem, which needs to be discussed explicitly. Third, the Asian evidence is very sensitive to country selection and estimation method. The factors driving sustainability vary across countries, as evidenced in studies of 10 or 12 Asian economies, four South Asian economies or selected Belt and Road economies. There has been recent evidence that supports the relevance of heterogeneity (J. Zhang et al., 2026).

Kansel et al. (2026) adopt second generation panel procedures specifically to address cross-sectional dependence and distributional differences in sustainability outcomes, by adjusting the net savings for Pacific Asian economies. Similarly, H. Zhang et al. (2026) report that there are significant differences among Asian countries in their climate and sustainable-development trajectories. The present study thus complements the literature by analyzing 21 Asian economies over the period from 2000 to 2021, across multiple Asian subregions, with a modified adjusted net savings measure, which does not include the direct deduction for CO₂ damage. It then compares the long run relationship between climate-change pressure and sustainable development, taking into account the economic development, trade openness, urbanization, and natural-resource rents, while explicitly accounting for cross-country dependence and heterogeneous response.

Data and Methods

Data and Sample

The sample includes representation from Eastern, Southeast, Southern, Central and Western Asia, and includes significant income differences, as well as differences in the level of urbanization and differences in the levels of resource reliance and emissions intensity. Given the geographical level of analysis, inclusion was based on the availability of continuous observations for the end-of-year variables for the 2000–2021 period, yielding a well-balanced panel of 462 country-year observations.

The adjusted net savings (ANS) is a calculation that incorporates net national savings as well as education expenditure and subtracts energy and mineral depletion, forest depletion, carbon-dioxide damage, and particulate-emission damage, and forms the basis for sustainable development. The measurement adjustment was done because the amounts of carbon-dioxide damage are already accounted for in the standard ANS, and greenhouse gas is the chief

explanatory variable in this study. In an effort to minimize this direct accounting overlap, a modified version of the sustainability measure was created, which is called SD*. A modified sustainability measure, SD* was developed as follows:

$$SD_{it}^* = ANS_{it} + CO2D_{it}$$

where CO2D is the World Bank carbon-dioxide damage (\$% of GNI). Hence, SD* still has the original capital-based structure of the adjusted net savings but without the direct carbon-damage deduction. Climate-change pressure CC is the total GHG emissions except LULUCF per capita. The control variables in the table are the natural logarithm of GDP per capita, lnGDP; the share of the population living in urban areas, URB; and the total amount of natural-resource rents as a percentage of GDP, NRR. The final variables are defined and provided in the following Table 1.

Table 1: Variable Measurement

Symbol	Variables	Measurement	Unit
SD*	Sustainable Development	Adjusted net savings + carbon dioxide damage	% of GNI
CC	Climate-Change pressure	Total greenhouse gas emissions excluding LULUCF per capita	t CO ₂ e per capita
lnGDP	Economic Development	Natural log of GDP per capita (constant 2015 US\$)	Natural log
TRD	Trade Openness	Trade	% of GDP
URB	Urbanization	Urban population	% of total population
NRR	Natural-resource dependence	Total natural resources rents	% of GDP

Note. All variables are from the World Development Indicators (WDI). SD* is a study-specific constructed measure and is not a separately published WDI indicator.

Descriptive Statistics

The descriptive statistics for variables used in the final model are presented in Table 2. Mean value of modified adjusted net savings SD* is 14.203% of GNI; ranging from -16.752 to 37.037. The negative minimum value means that some country-year observations had a decrease in their overall capital base. The mean of the climate change pressure CC is 6.001 tonnes of CO₂-equivalent per capita, the range from 0.746 to 23.288, suggesting large variations in the greenhouse gas intensity of the sampled economies. The mean of lnGDP is equal to 8.266 and the mean of trade openness is equal to 81.766% of GDP. Urban population accounts for an average of 53.636% of total population, natural-resource rents average 5.516% of GDP. The relatively high standard deviations of selected variables further confirm the significant economic and structural variations between the 21 Asian economies.

Table 2: Descriptive Statistics

Variable	N	M	SD	Minimum	Maximum
SD*	462	14.203	9.118	-16.752	37.037
CC	462	6.001	4.801	0.746	23.288
lnGDP	462	8.266	1.216	6.305	10.616
TRD	462	81.766	40.962	19.275	220.407
URB	462	53.636	19.527	18.624	91.874
NRR	462	5.516	8.449	0.001	43.041

Note. M = mean; SD = standard deviation. All variables have 462 observations.

Descriptive Trends and Preliminary Patterns

The graph presents the evolution of the sample of sustainable development that presented in figure 1. The average SD* rose significantly in the early 2000s and has fluctuated somewhat since the relatively high level seen around 2007, with a marked drop at the end of the sample period.

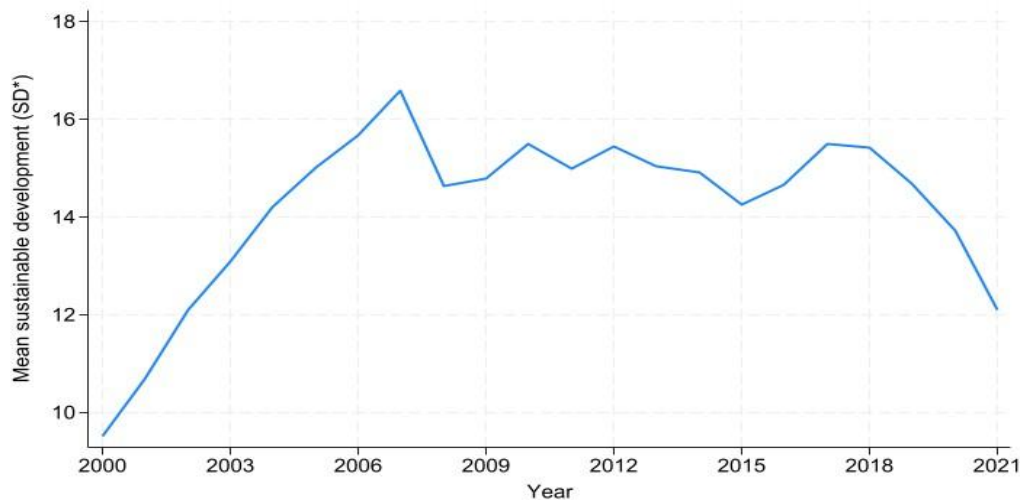


Figure 1. Trend in Sustainable Development Across 21 Asian Economies, 2000–2021

The overall trend in the climate-change pressure is upward as shown in figure 2 during the study period. The per capita GHG emissions rose from around 5 tonnes of CO₂-equivalents in 2000 to over 6.5 tonnes at the end of the sample period but with some temporary decreases in between.

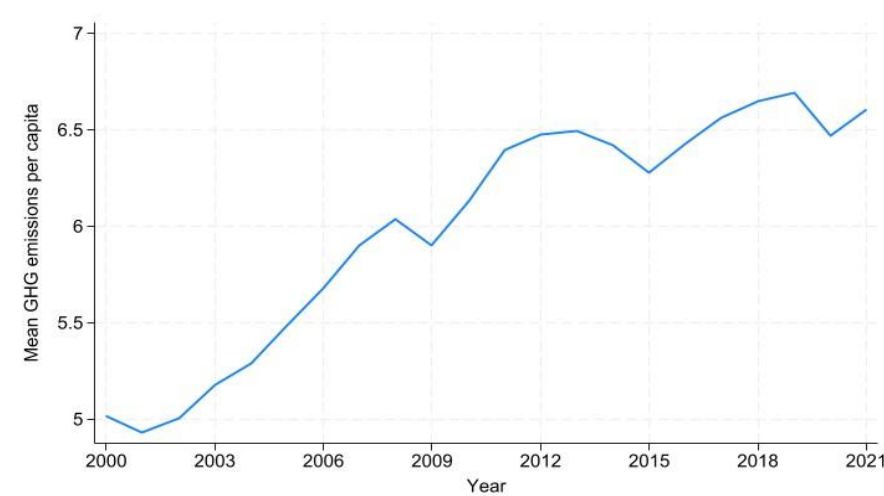


Figure 2. Trend in Climate-Change Pressure Across 21 Asian Economies, 2000–2021

The climate change pressure and sustainable development is compared across countries in Figure 3. The fitted line shows a negative association between the two variables that is only conditional on the other variable, in this case, average GHG emissions per capita: economies with a higher average GHG emission per capita tend to have lower average SD* per capita. There is, however, a large country dispersion, indicating large cross-country heterogeneity. This descriptive pattern is similar to the case of an econometric model with heterogenous slopes and common cross-sectional factors.

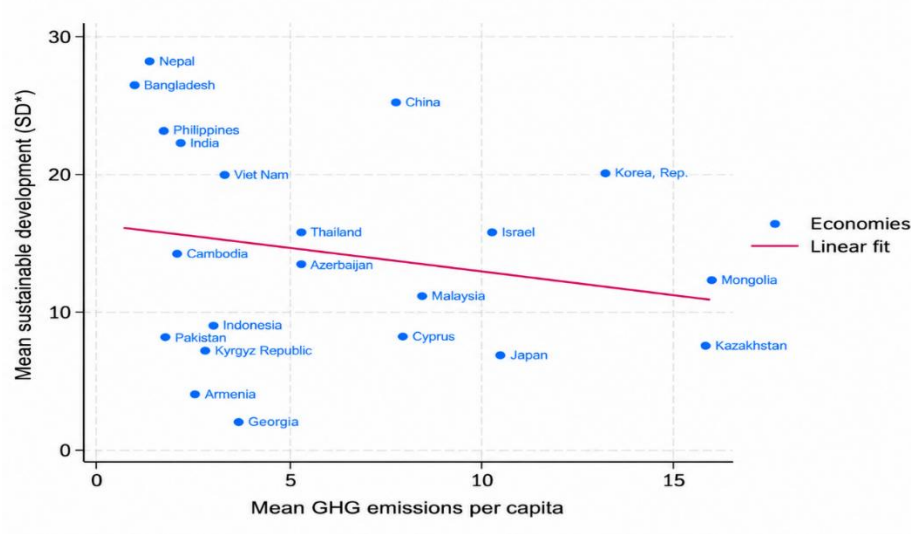


Figure 3. Climate-Change Pressure and Sustainable Development Across 21 Asian Economies

Empirical Model

The relationship for baseline model is given as:

$$SD_{it}^* = \alpha_i + \beta_1 CC_{it} + \beta_2 \ln GDP_{it} + \beta_3 TRD_{it} + \beta_4 URB_{it} + \beta_5 NRR_{it} + \varepsilon_{it}$$

where i represents country and t represents year. The main coefficient of interest is β_1 which captures the association between climate-change pressure and sustainable development. The negative coefficient is anticipated due to the fact that high climate pressure can be linked to high environmental expenses and decrease in sustainable fortune amassing. Consideration of country-specific coefficients is allowed, as the climate pressure effect might vary between different economies with different development structures and resource profiles.

Econometric Methodology

The empirical approach is based on second generation panel data techniques. This is significant because countries in Asia can be hit at the same time by common shocks like global energy-price fluctuations, financial crisis, technological advances and regional environmental pressures. The Pesaran cross sectional dependence test (CSD), as included in the *xtcsd* procedure (De Hoyos & Sarafidis, 2006), was used for initial cross-sectional dependence. After estimation of CCE, residual weak cross-sectional dependence was assessed using Pesaran (2015) framework.

Second, the integration properties of the variables are tested based on the unit root test developed by Pesaran (2007) and applied in the present study for the first time. While first-generation panel unit root tests are not suitable for countries when there are common factors affecting countries, then CIPS is suitable. Third, the long-run association among the non-stationary variables is analyzed by applying the error-correction based on a panel cointegration test developed by Westerlund (2007). The test examines the effects of deviation from long run equilibrium over time and will offer both group and panel statistics. Inference is mainly carried out based on bootstrap-robust probabilities due to the presence of cross-sectional dependence. Fourth, the homogeneity of the coefficients is tested with the Pesaran and Yamagata (2008) slope-homogeneity test. This is a procedure to determine if it is reasonable to assume that the parameters of the slope are the same for the different countries. If the homogeneity of the slope is rejected, then the estimation models that allow country specific responses can be used.

As shown in the previous section, the cross-sectional dependence and the slope heterogeneity are present, thus the main long-run coefficients are estimated using the Common Correlated Effects Mean Group (CCMG) approach proposed by Pesaran (2006). The mean-group structure permits different country-specific coefficients, and CCE adds country-specific averages of the dependent and explanatory variables to the country-specific regressions to model unobserved common factors. Under significant cross-sectional dependence and parameter heterogeneity, the method is found to be effective by Pesaran (2006). The model is estimated with the *xtdcce2* procedure developed by

Dietz et al. (2007) which allows for the practical implementation of the CCE framework and also facilitates the estimation of heterogeneous panels. The final coefficient estimates are obtained using 400 replications for the bootstrap inference. Lastly, the Pesaran weak-dependence test is used to check if the residual of the estimated CCE model has absorbed the remaining common cross-sectional dependence.

Empirical Results

The correlation matrix is given in Table 3. There is preliminary evidence for an inverse relationship with the correlation between climate change pressure and sustainable development being negative: $r = -0.175$, $p < .01$. This simple correlation is not adjusted for other economic factors or cross-country heterogeneity, however. Compared to other variables, relatively high correlations are seen between urbanization and $\ln\text{GDP}$ ($r = 0.836$) and between CC and $\ln\text{GDP}$ ($r = 0.698$). The mean variance inflation factor is 2.71 and the maximum VIF is 4.34 for $\ln\text{GDP}$. These values do not mean that the regressors are highly correlated.

Table 3: Pearson Correlations and Variance Inflation Factors

Variable	1	2	3	4	5	6	VIF
1. SD*	—						—
2. CC	-.175**	—					2.94
3. $\ln\text{GDP}$	-.173**	.698**	—				4.34
4. TRD	-.188**	.155**	.083	—			1.12
5. URB	-.198**	.651**	.836**	-.038	—		3.61
6. NRR	-.136**	.366**	-.047	.244**	-.028	—	1.52

Note. Pearson correlations are based on $N = 462$. * $p < .05$. ** $p < .01$. Mean VIF = 2.71; maximum VIF = 4.34.

Cross-Sectional Dependence and Slope Heterogeneity

The cross-sectional dependence and slope homogeneity tests are reported in Table 4. The Pesaran CD statistic is 3.395 at $p < .001$ (which is less than the usual cutoff of 5). This means that shocks to one Asian economy might be associated with events in other economies in the sample. The slope-homogeneity tests also fail to accept the hypothesis that the coefficients of the explanatory variables are the same in different countries. The Delta statistic is 3.248, $p = .001$, while the adjusted Delta statistic is 3.978, $p < .001$. The results in this paper demonstrate the presence of cross-sectional dependence and heteroscedastic slopes in the panel. Hence, an estimator of common shocks that allows for country-specific responses is more beneficial than the traditional homogeneous panel estimator.

Table 4: Cross-Sectional Dependence and Slope Heterogeneity Diagnostics

Test	Statistic	Value	p	Decision
Pesaran cross-sectional dependence	CD	3.395	< .001	Cross-sectional dependence detected
Pesaran-Yamagata slope homogeneity	Delta	3.248	.001	Reject homogeneous slopes
Pesaran-Yamagata slope homogeneity	Adjusted Delta	3.978	< .001	Reject homogeneous slopes

Note. The Pesaran CD statistic is based on the final fixed-effects specification; the average absolute off-diagonal residual correlation is 0.329. The slope-homogeneity test follows Pesaran and Yamagata (2008).

Panel Unit-Root Results

The results of the unit-root tests are reported in Table 5. SD^* is non-stationary at level but stationary after first differencing, while trade openness and natural-resource rents are stationary at level. Hence these variables are said to be $I(1)$. The two variables that are not changing, in contrast, are stationary at level and are called $I(0)$. It is important to note that there are no variables of order two ($I(2)$) in the above variables. Hence, the relationship between $I(0)$ and $I(1)$ variables can be further explored. The CCE framework has been extended to panels with non-stationary multifactor structures, thus allowing its use when common factors and regressors exhibit unit-root behavior (Kapetanios et al., 2011).

Table 5: Cross-Sectionally Augmented IPS (CIPS) Panel Unit-Root Tests

Variable	Level CIPS	First-difference CIPS	Integration order
SD^*	-1.730	-3.973***	$I(1)$
CC	-1.473	-3.909***	$I(1)$
$\ln GDP$	-2.345***	-2.813***	$I(0)$
TRD	-1.314	-3.447***	$I(1)$
URB	-2.320***	-1.491	$I(0)$
NRR	-1.766	-4.132***	$I(1)$

Note. The CIPS null hypothesis is that all cross-sectional units contain a unit root. Critical values with a constant are -2.07 (10%), -2.15 (5%), and -2.30 (1%). *** indicates rejection at the 1% level. Because $\ln GDP$ and URB are stationary at level, their first-difference results are not required for classification.

Panel cointegration

The cointegration results from the Westerlund test are given in Table 6. Since there is cross sectional dependence, higher weightage has been given to the bootstrap robust probabilities. lnGDP and URB are stationary at level so they are not subjected to the Westerlund test while SD, CC, TRD and NRR are stationary at I(1). The stationary variables are kept as controls in the final CCE-MG model. The Westerlund specification is used with 1 lag, 0 leads and 400 bootstrap replications: The results are: The robust p-value statistic for the Westerlund specification is -11.509 with a robust p value of .008, and the statistic for the Pa specification is -6.276 with a robust p value of .025. Both the tests of the panel statistics reject the null hypothesis of no cointegration at the 5% level. The Gt statistical test is not as strong as the Gt test at the 10% level ($p=.060$), and Ga does not reject the null ($p=.305$).

Overall, the findings contribute to the existence of a panel level long run relationship between the variables SD, CC pressure, T and NRD. The poorer performance in the group statistics is also in line with the previous evidence of the divergence of adjustment processes between the different economies.

Table 6: Westerlund Error-Correction Panel Cointegration Test

Statistic	Value	Z	p	Robust p
Gt	-2.268	-0.170	.433	.060
Ga	-5.594	3.500	1.000	.305
Pt	-11.509	-2.562	.005	.008
Pa	-6.276	0.827	.796	.025

Note. Null hypothesis: no cointegration. Robust p values are based on 400 bootstrap replications. The panel statistics Pt and Pa reject the null at the 5% level; Gt is marginal at the 10% level, whereas Ga does not reject. The pattern supports panel-level cointegration while indicating heterogeneous country-specific adjustment.

Long-run CCE mean-group estimates

Common correlated effects mean group bootstrap results are presented in Table 7. The estimated point value of the parameter CC is -3.910 . In units, this translates to a 3.91 percentage point reduction in SD given a one-tonne rise in GHG emissions per capita, control for other regressors held constant. The estimate, however, is statistically imprecise $p = .270$; 95% CI $[-10.853, 3.034]$ and is not statistically different from zero. Thus, the analysis does not offer sufficient statistical evidence to conclude that pressure due to climate change has a uniform long-term impact on sustainable development in all the 21 economies.

However, the direction of the relationship remains in the same direction as expected and as reported by other studies; as in the case of Hunjra et al. (2023) and Khan et al. (2025) that found an

inverse relationship between environmental degradation and sustainable development. The results were not significant in this study because there was the high degree of heterogeneity in the 21 Asian economies identified by the slope-homogeneity tests. The estimated sign is in accordance with H1; however, the coefficient is not statistically significant, thus H1 is not statistically supported in the full-sample long-run model.

Table 7: Final Long-Run Common Correlated Effects Mean-Group Estimates

Predictor	B	Bootstrap SE	z	p	95% CILL	95% UL	CI
CC	-3.910	3.543	-1.10	.270	-10.853	3.034	
lnGDP	43.014	19.512	2.20	.027	4.771	81.257	
TRD	-0.028	0.072	-0.40	.692	-0.169	0.112	
URB	-9.058	7.103	-1.28	.202	-22.980	4.864	
NRR	-0.420	4.260	-0.10	.921	-8.769	7.929	

Note. Dependent variable = SD*. Bootstrap inference is based on 400 cross-sectional replications (seed = 12345). N = 462; 21 countries; T = 22. Model R² = .36; mean-group R² = .83; root MSE = 2.12. Only lnGDP is statistically significant at the 5% level. The negative CC coefficient is not statistically significant.

The most obvious impact is the economic development. The value of the coefficient of lnGDP is 43.014 and statistically significant at the 5% level $p=.027$. Since GDP is used in the model in its log form, a 1% rise in GDP per capita corresponds to a 0.43% rise in SD*. This implies that an increase in economic growth has positive effects on sustainable accumulation of wealth. The result is in line with the results of Koirala & Pradhan (2020), Wei & Huang (2022) and Khan et al. (2025).

The coefficient of trade openness is small and negative, -0.028 , $p=.692$, and this does not have enough statistical power to conclude that there is a long run relationship between trade openness and sustainable development. Likewise, urbanization's coefficient value is negative, -9.058 , although it is not statistically significant, $p=.202$. The natural-resource rents also have a negative sign, -0.420 , but are not significant to the model at $p=.921$. Therefore, while trade, urbanization and resource dependence have negative estimated signs, no sign is statistically significant enough in this sample to support the conclusion of an average long-run effect for this. Overall, the main estimation suggests that the estimated climate-pressure effect is statistically uncertain, negative and variable, with the only statistically significant estimated average long-run coefficient being that of lnGDP in the final specification.

Post-Estimation Diagnostic

Table 8 shows the results of the residual cross sectional dependence test. Pesaran CD statistic following CCE estimation is -0.133 $p=0.894$. The null hypothesis (weak residual cross-sectional

dependence) is thus not rejected. This outcome is significant since a strong cross-sectional dependence was identified prior to the estimation. The estimated residual CD statistic is -0.133 ($p=.894$) and indicates no evidence against the null of weak residual cross-sectional dependence. This is in line with the CCE specification having significantly reduced the common dependence that was originally detected in the initial model.

Table 8: Post-Estimation Residual Cross-Sectional Dependence Test

Test	CD statistic	p	Conclusion
Pesaran weak cross-sectional dependence	-0.133	$.894$	Fail to reject weak residual dependence

Note. Null hypothesis: errors are weakly cross-sectionally dependent. The nonsignificant result indicates that the final CCE specification adequately absorbs the strong common cross-country dependence present in the raw panel.

Based on the empirical analysis the following three findings emerge. First, there is an "adverse but statistically insignificant long-run correlation between climate-change pressure and sustainable development. Secondly, the relationship between economic development and SD is positive and has a statistical significance. Third, high level of slope heterogeneity suggests that there is a significant variation in sustainability reactions between Asian economies. The results show that the climatic pressure-sustainable development linkage could not be taken as homogenous for the region.

Discussion

The findings offer a tentative but significant insight into the linkages between climate-change stress and sustainable development in Asian economies. There is a negative long-run coefficient for climate-change pressure, but it is not statistically significant. The direction is consistent with two other studies, Hunjra et al. (2023) found significant drop in adjusted net savings for developing countries due to environmental degradation and Khan et al. (2025) noted that carbon emissions are one of the key long-run determinants of South Asia's sustainable development. The results of the present work thus confirm previous work in direction, but not in statistical strength. This difference is feasible due to the larger and more diverse sample used in this study.

The study includes 21 economies in various Asian subregions and with widely divergent production patterns, incomes, resource endowments and emissions. Both the slope-homogeneity test results reject the hypothesis of common coefficients among countries, revealing that the relationships of the model are not common in the long run. The significance of the average CC coefficient should thus be taken with a pinch of salt, as it does not prove the absence of country-specific associations, but also the joint slope test does not prove the absence of heterogeneity in the CC coefficient alone. This interpretation is supported by recent Asian evidence. The correlation between pressures on

carbon and sustainable development is different by country and by level of sustainable development, according to Liu and Liu (2025).

Similarly, H. Zhang et al. (2026) demonstrate that the sustainability impacts of climate action in Asia vary significantly by country, and a uniform regional transition is not guaranteed to have the same impacts on all countries. Therefore, the average climate coefficient, which is rather small, should not be taken as a sign that climate pressure has no long-term impact; rather, it indicates that the impact of climate pressure is not uniform across the 21 economies. It is possible that this may be due to the fact that the construction of SD^* accounts for the more conservative estimated climate effect in comparison to some previous studies. Even if the carbon-damage costs are already included in the standard ANS measure, many studies still take both the standard adjusted net savings and CO_2 emissions. The carbon-dioxide damage factor is reintroduced into standard ANS, which removes one source of direct accounting overlap of the dependent variable and the emissions measure from the study. This allows a more straightforward specification to be used for qualifying the general link between emissions and sustainable wealth, but it does not isolate this change as a proxy for differences in results from previous empirical studies.

The most effective outcome is achieved as a result of economic development. The GDP per capita is positively and significantly related to sustainable development. The results are similar to those of Koirala and Pradhan (2020), who find that per capita income makes a significant difference in adjusted net savings of 12 Asian economies. Wei and Huang (2022) further found that economic growth has a positive impact on adjusted net savings in 10 Asian countries. The same can be observed by Wang et al. (2022), in which per capita income is a positive influence on inclusive green growth in Belt and Road economies. The coefficient on GDP per capita is 0.43% and the coefficient on SD is 1.00, meaning that an increase in GDP per capita of 1% is roughly correlated with an increase in SD of 0.43 percentage point, *ceteris paribus*.

The indicators of trade openness are negative, but not statistically significant. This finding is in line with more recent research finding that trade can generate costs in the form of sustainability when growth is dependent on activities that are resource or polluting intensive. According to Liu and Liu and Liu (2025), trade openness is negatively related to sustainable development over a number of sustainability endpoints while Razak et al. (2025) reveal a negative long-run relationship between trade openness and adjusted net savings in ASEAN economies. Trade effect's non-significance in the present study indicates that the trade effect varies in different countries due to different export structures, technologies and environmental regulations.

Long-run relationship with urbanization is also negative but not significant. This is also consistent with Wang et al. (2022), who found that urbanization hinders inclusive green growth in countries along the Belt and Road or countries facing urban expansion with environmental pressure. Again, the low value here indicates heterogeneity; in some economies, it could be environmental stress that comes with urbanization, while in others, it may be increasing efficiency in the environment, productivity and access to services.

There is a similar pattern for natural-resource rents: a negative coefficient, which is not statistically significant. Koirala and Pradhan (2020) find in Asia that natural-resource rents have a significant negative association with adjusted net saving, and van Krevel and Peters (2024) illustrate that energy-resource rents and exports, in general, lower genuine saving, but with the important caveat that the effect depends on institutions and the way in which resource income is saved. This is a helpful account of the weak average impact observed here: the sustainability impact of resource dependence is likely to vary between those economies that spend resource revenues and those that successfully transform them to human and produced capital.

In general, the findings indicate that the relationship of the three growth dimensions with sustainable wealth is most consistent and positive for economic development, while the relationship of climate pressure, trade and natural-resource dependence with sustainable wealth is mixed across Asian economies and urbanization is negative. The key contribution is not to say climate pressure does not affect, but to provide evidence that the long-term sustainability impact of pressure is not even across the region. This understanding is rebounded by recent Asian studies that have focused on country-specific policies and actions on climate and sustainability.

Conclusion and Policy Implications

The long-run relationship between greenhouse gas emissions (GHGs) and sustainable development in 21 economies in Asia during 2000–2021 is explored in this study. A modified adjusted net savings indicator, SD^* , is used to measure sustainable development, which includes the carbon-dioxide damage component added to the standard adjusted net savings indicator. This adjustment minimizes the direct accounting overlap between the sustainability indicator and the emissions variable to help focus the analysis on the overall emissions to sustainable wealth accumulation relationship.

The empirical method takes the key characteristics of the panel data into consideration. The findings show that Asian economies are subject to common regional shocks and global shocks, but they do not react to these shocks in the same manner, showing important cross-sectional dependence and strong slope heterogeneity. The Westerlund test shows that there is panel level cointegration, thus long-run relationship among key non-stationary variables. A Common Correlated Effects Mean Group estimator is thus employed to correct for common factors and for country-specific variation.

The key results are easy to see, but need to be treated with caution. The long-run coefficients of the greenhouse gases are negative, meaning that the higher the pressure of greenhouse gas emissions, the lower the sustainable wealth. But the coefficient is not statistically significant following the bootstrap inference. The study does not, consequently, prove there is a consistent adverse emissions effect throughout the 21 economies studied. This result by itself is important as it indicates that the sustainability impacts of emissions are far from uniform and can depend on the variations in industrial structure, energy systems, resource dependency, income levels, and institutional conditions. Modified adjusted net savings, on the other hand, have a positive and statistically

significant long-run relationship to GDP per capita. This means that more developed economies can build more productive and human capital, but that economic growth is not necessarily sustainable.

The findings have a number of policy implications. First, it is not likely that a common regional climate strategy would be equally effective in all Asian economies. There is a need for countries that have more carbon-intensive production structures to have stronger incentives for cleaner technology, energy efficiencies, and low carbon industrial transformation. Policies to direct resource revenues towards investments that enhance human, social, and productive capital in economies with a high reliance on fossil fuels or other extractive activities may also be needed to ensure that the depletion of natural capital is more effectively translated into long-term wealth.

Second, it is clear that the positive relationship between income and sustainable wealth implies that climate policy must be designed to encourage not hinder productive investments. This is particularly the case for lower income economies, where the pace of emission reduction without sufficient financial and technological means may create stress on the development capacity. Policies and actions to increase access to cleaner technologies, to green infrastructure, to climate finance and to international technology transfer can contribute to balancing environmental objectives while maintaining the process of capital accumulation.

Third, the high level of heterogeneity suggests policy design should be tailored to the countries situation. Combination of fiscal, energy, industrial and environmental policies may be necessary in different economies with high emission rates, rapid urbanization and high dependence on natural resources. Regional cooperation continues to be valuable, including through collaboration on technology transfer, climate finance, energy-market integration and knowledge sharing, while adapting it to be flexible enough to reflect national circumstances. There are also a number of limitations to the study. Emissions-based proxy for climate pressure is not a direct measure of climate exposure, vulnerability or realized climate damages, which is greenhouse gas emissions. The sample consists of a limited number of economies (21) that have been observed on an annual basis, and the time dimension is relatively short, making it difficult to investigate structural shifts in the very long-term. Furthermore, the analysis includes an estimation of the average long run associations and does not account for causal effects.

Limitations of the Study

Further studies might extend the analysis by incorporating indicators of emissions with actual climate exposure, climate vulnerability, extreme weather or adaptation capacity. It would further be helpful to explore if the relationship varies by income group, resource dependent and resource poor economies and high and low emission countries. The longer panels, country-specific models, and a distributional approach could help shed more light on the divergent climate-related sustainability outcomes in Asia. The overall finding of the study indicates that the connection between the GHG emission and sustainable development in Asia is not consistent. It should be noted that the emissions coefficient is negative, but there is no evidence for a common statistically

significant effect throughout the entire sample. The more robust conclusion is that economic development is positively related to sustainable wealth, but that there is considerable cross-country heterogeneity. This implies that the pathway towards sustainability in Asia is not only about mitigating CO₂ emissions, but also what changes are needed to be able to shift income, resources, technology and investment into sustainable forms of wealth.

References

1. Abid, I. (2025). Balancing growth and sustainability: The role of economic factors in adjusted net savings in South Asia. *International Journal of Sustainable Development and Planning*, 20(4), 1487–1497. <https://doi.org/10.18280/ijstdp.200412>
2. Adshead, D., Paszkowski, A., Gall, S. S., Peard, A. M., Adnan, M. S. G., Verschuur, J., & Hall, J. W. (2024). Climate threats to coastal infrastructure and sustainable development outcomes. *Nature Climate Change*, 14, 344–352. <https://doi.org/10.1038/s41558-024-01950-2>
3. Boos, A. (2015). Genuine savings as an indicator for "weak" sustainability: Critical survey and possible ways forward in practical measuring. *Sustainability*, 7(4), 4146–4182. <https://doi.org/10.3390/su7044146>
4. De Hoyos, R. E., & Sarafidis, V. (2006). Testing for cross-sectional dependence in panel-data models. *The Stata Journal*, 6(4), 482–496. <https://doi.org/10.1177/1536867x0600600403>
5. Dietz, S., Neumayer, E., & De Soysa, I. (2007). Corruption, the resource curse and genuine saving. *Environment and Development Economics*, 12(1), 33–53. <https://doi.org/10.1017/s1355770x06003378>
6. Ferreira, S., & Vincent, J. R. (2005). Genuine savings: Leading indicator of sustainable development? *Economic Development and Cultural Change*, 53(3), 737–754. <https://doi.org/10.1086/426834>
7. Ganhane, J. J., & Stage, J. (2024). Resource rents, genuine savings and sustainable development: Revisiting the evidence. *Sustainability*, 16(15), 6535. <https://doi.org/10.3390/su16156535>
8. Gillani, S., Wang, F., Sharif, A., Rexhepi, G., & Shafiq, M. N. (2026). The Role of Environmental Concern in Shaping Support for Green Business Practices: Evidence From the World Values Survey. *Business Strategy and the Environment*. <https://doi.org/10.1002/bse.70852>
9. Greasley, D., Hanley, N., Kunnas, J., McLaughlin, E., Oxley, L., & Warde, P. (2014). Testing genuine savings as a forward-looking indicator of future well-being over the very long run. *Journal of Environmental Economics and Management*, 67(2), 171–188. <https://doi.org/10.1016/j.jeem.2013.12.001>
10. Hanley, N., Dupuy, L., & McLaughlin, E. (2015). Genuine savings and sustainability. *Journal of Economic Surveys*, 29(4), 779–806. <https://doi.org/10.1111/joes.12120>
11. Hunjra, A. I., Hassan, M. K., Ben Zaied, Y., & Managi, S. (2023). Nexus between green finance, environmental degradation, and sustainable development: Evidence from

- developing countries. *Resources Policy*, 81, 103371. <https://doi.org/10.1016/j.resourpol.2023.103371>
12. Huo, W., Ullah, M. R., Zulfiqar, M., Parveen, S., & Kibria, U. (2022). Financial development, trade openness, and foreign direct investment: A battle between the measures of environmental sustainability. *Frontiers in Environmental Science*, 10, 851290. <https://doi.org/10.3389/fenvs.2022.851290>
13. Jiang, W., Shafiq, M. N., Gillani, S., & Saeed, M. (2026). Green electricity adoption as a catalyst for mitigating the ecological pressure of economic complexity in BRICS economies. *Scientific Reports*. <https://doi.org/10.1038/s41598-026-65971-x>
14. Kansel, Z. C., Ozdeser, H., & Seraj, M. (2026). Factors influencing sustainable development in Pacific Asia: A quantile panel analysis. *Sustainability*, 18(7), 3197. <https://doi.org/10.3390/su18073197>
15. Kapetanios, G., Pesaran, M. H., & Yamagata, T. (2011). Panels with non-stationary multifactor error structures. *Journal of Econometrics*, 160(2), 326–348. <https://doi.org/10.1016/j.jeconom.2010.10.001>
16. Khan, I., Mahmood, T., Ahmad, S., & Shil, N. C. (2025). Factors impacting sustainable development in selected South Asian economies: Empirical evidence. *Sustainable Futures*, 9, 100557. <https://doi.org/10.1016/j.sfsr.2025.100557>
17. Koirala, B. S., & Pradhan, G. (2020). Determinants of sustainable development: Evidence from 12 Asian countries. *Sustainable Development*, 28(1), 39–45. <https://doi.org/10.1002/sd.1963>
18. Liu, H., & Liu, Y. (2025). Agricultural carbon footprints, renewable energy and sustainable development in Asia. *Scientific Reports*, 15, 34429. <https://doi.org/10.1038/s41598-025-17491-3>
19. McLaughlin, E., Ducoing, C., & Oxley, L. (2025). Tracing sustainability in the long run: Genuine savings estimates, 1850–2018. In N. Z. Muller, E. P. Fenichel, & M. Bohman (Eds.), *Measuring and Accounting for Environmental Public Goods: A National Accounts Perspective* (pp. 63–100). University of Chicago Press. <https://doi.org/10.7208/chicago/9780226839363.003.0005>
20. Nazir, R., Gillani, S., Shafiq, M. N., Nasrullah, M. J., & Shahzad, M. F. (2026). Fiscal and monetary policy for green growth: the role of institutional quality in South Asia. *Environment, Development and Sustainability*, 1–35. <https://doi.org/10.1007/s10668-026-07422-1>
21. Organization, W. M. (2026). *State of the Climate in Asia 2025*. <https://wmo.int/resources/publication-series/state-of-climate-asia/state-of-climate-asia-2025>
22. Pesaran, M. H. (2006). Estimation and inference in large heterogeneous panels with a multifactor error structure. *Econometrica*, 74(4), 967–1012. <https://doi.org/10.1111/j.1468-0262.2006.00692.x>
23. Pesaran, M. H. (2007). A simple panel unit root test in the presence of cross-section dependence. *Journal of Applied Econometrics*, 22(2), 265–312. <https://doi.org/10.1002/jae.951>

24. Pesaran, M. H. (2015). Testing weak cross-sectional dependence in large panels. *Econometric Reviews*, 34(6-10), 1089–1117. <https://doi.org/10.1080/07474938.2014.956623>
25. Pesaran, M. H., & Yamagata, T. (2008). Testing slope homogeneity in large panels. *Journal of Econometrics*, 142(1), 50–93. <https://doi.org/10.1016/j.jeconom.2007.05.010>
26. Pezzey, J. C. V. (2024). Adjusted net savings needs further adjusting: Reassessing human and resource factors in sustainability measurement. *Journal of Environmental Economics and Management*, 127, 102984. <https://doi.org/10.1016/j.jjeem.2024.102984>
27. Pillarisetti, J. R. (2005). The World Bank's 'genuine savings' measure and sustainability. *Ecological Economics*, 55(4), 599–609. <https://doi.org/10.1016/j.ecolecon.2005.01.018>
28. Rana, M. (2025). Climate risk and resilience: Evaluating their impact on sustainable development in South Asia. *Theoretical and Applied Climatology*, 156, 319. <https://doi.org/10.1007/s00704-025-05531-x>
29. Razak, A. R., Saudi, N. D. S., Fernandes, A. A. R., Idris, A., & Arnan Rahman, A. M. (2025). The impact of trade on environmental quality and sustainable development in ASEAN region. *International Journal of Energy Economics and Policy*, 15(6), 638–647. <https://doi.org/10.32479/ijeep.21298>
30. Sharif, A., Shafiq, M. N., Gillani, S., Harymawan, I., & Cahyono, S. (2026). Industrial robot adoption and environmental sustainability: Technological and institutional pathways to sustainable development. *Technological Forecasting and Social Change*, 233, 124874. <https://doi.org/10.1016/j.techfore.2026.124874>
31. Sui, X., Sun, Z., Gillani, S., & Shafiq, M. N. (2026). FinTech and resource utilization: a governance-driven approach to managing ecological footprint in top emerging markets. *Humanities and Social Sciences Communications*. <https://doi.org/10.1057/s41599-026-08446-8>
32. Sun, X., Dong, Y., Shafiq, M. N., Gago-de Santos, P., & Gillani, S. (2025). Economic policy uncertainty and environmental quality: unveiling the moderating effect of green finance on sustainable environmental outcomes. *Humanities and Social Sciences Communications*, 12(1), 801. <https://doi.org/10.1057/s41599-025-05212-0>
33. Tokimatsu, K., Dupuy, L., & Hanley, N. (2019). Using genuine savings for climate policy evaluation with an integrated assessment model. *Environmental and Resource Economics*, 72, 281–307. <https://doi.org/10.1007/s10640-018-0292-2>
34. van Kreveld, C., & Peters, M. (2024). How natural resource rents, exports, and government resource revenues determine genuine savings: Causal evidence from oil, gas, and coal. *World Development*, 181, 106657. <https://doi.org/10.1016/j.worlddev.2024.106657>
35. Wang, F., Gillani, S., Balsalobre-Lorente, D., Shafiq, M. N., & Khan, K. D. (2025). Environmental degradation in South Asia: Implications for child health and the role of institutional quality and globalization. *Sustainable Development*, 33(1), 399–415. <https://doi.org/10.1002/sd.3124>
36. Wang, F., Gillani, S., Razaq, A., Nazir, R., Shafiq, M. N., & Li, B. (2024). Synergistic impacts of technological advancement and environmental hazards on social change and human

- well-being in South Asia. *Technological Forecasting and Social Change*, 208, 123721. <https://doi.org/10.1016/j.techfore.2024.123721>
37. Wang, F., Gillani, S., Sharif, A., Shafiq, M. N., & Farooq, U. (2025). Balancing well-being and environment: The moderating role of governance in sustainable development amid environmental degradation. *Journal of environmental management*, 386, 125803. <https://doi.org/10.1016/j.jenvman.2025.125803>
38. Wang, N., Ullah, A., Lin, X., Zhang, T., & Mao, J. (2022). Dynamic influence of urbanization on inclusive green growth in Belt and Road countries: The moderating role of governance. *Sustainability*, 14(18), 11623. <https://doi.org/10.3390/su141811623>
39. Wei, Z., & Huang, L. (2022). Does renewable energy matter to achieve sustainable development? Fresh evidence from ten Asian economies. *Renewable Energy*, 199, 759–767. <https://doi.org/10.1016/j.renene.2022.07.101>
40. Westerlund, J. (2007). Testing for error correction in panel data. *Oxford Bulletin of Economics and Statistics*, 69(6), 709–748. <https://doi.org/10.1111/j.1468-0084.2007.00477.x>
41. Xie, F., Zhang, M., Shafiq, M. N., & Mahmood, H. (2026). From Complexity to Sustainability: The Environmental Regulation Puzzle in Emerging Economies. *Sustainable Development*, 34(3), 3457–3476. <https://doi.org/10.1002/sd.70527>
42. Yang, X., Shafiq, M. N., & Gillani, S. (2026). Towards sustainable development: the synergistic impact of economic complexity, environmental regulation, and renewable energy on environmental performance in G20 economies. *International Environmental Agreements: Politics, Law and Economics*, 26(2), 387–416. <https://doi.org/10.1007/s10784-026-09717-0>
43. Yang, X., Shafiq, M. N., Nazir, R., & Gillani, S. (2024). Unleashing the influence mechanism of technology innovation and human development for ecological sustainability in emerging countries. *Emerging Markets Finance and Trade*, 60(10), 2276–2299. <https://doi.org/10.1080/1540496X.2024.2308180>
44. Yang, X., Shafiq, M. N., Nazir, R., & Gillani, S. (2025). Economic complexity and the green transition: integrating energy efficiency and digital technologies for sustainable restructuring. *Economic Change and Restructuring*, 58(6), 92. <https://doi.org/10.1007/s10644-025-09932-w>
45. Yang, X., Shafiq, M. N., Sharif, A., Gillani, S., & Zeng, X. (2024). Balancing progress and preservation: analyzing the role of technological innovation in mitigating environmental degradation caused by energy consumption in China. *Economic Analysis and Policy*, 84, 391–409. <https://doi.org/10.1016/j.eap.2024.09.001>
46. Zhang, H., Ou, Y., Ren, M., Sun, Y., & Wang, P. (2026). Progress on the Sustainable Development Goals in Asia requires ambitious climate targets combined with sustainability-focused measures. *Communications Earth & Environment*, 7, 126. <https://doi.org/10.1038/s43247-025-02970-2>
47. Zhang, J., Zhang, Y., Shafiq, M. N., Saeed, M., & Gillani, S. (2026). Economic Complexity, Green Innovation, and Environmental Performance: Evidence on Heterogeneity and

Structural Relationships in G20 Economies. *Complexity*, 2026(1), 5165968.
<https://doi.org/10.1155/cplx/5165968>